TECHWATCH

NOVEMBER 2019

Narrowing the field:
how human-machine teams will change

When fatigue is a matter of **life and death**

A new direction for education:
the technologies that will transform training

Giant leaps
for unmanned-kind

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QINETIQ

FOREWORD

Hello and welcome to the first issue of TechWatch by QinetiQ.

In order to adopt the very best innovations and processes in current and future operations, we need to keep in touch with developments in industries outside of our own. As a key partner to those in the defence, we understand this. We are very lucky to have global experts in dozens of fields of science and technology and using their knowledge, we have proven our ability to analyse the present and predict the future.

TechWatch is a comprehensive assessment of emerging technology. Our experts study technology developments and trends, whilst also considering the practical applicability of emerging tech in our customers' markets. Our team is highly engaged with academia, SMEs, large enterprise and of course the media. With a comprehensive understanding of defence and national security, we are well placed to guide you on where to place your technology bets for the future.

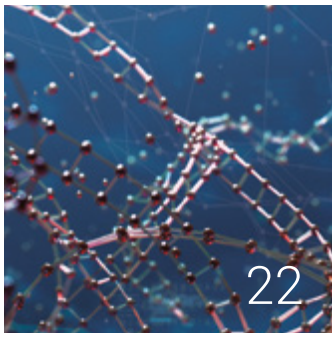
Each quarter, we will bring you a snapshot of the very latest technology developments news and its impacts, as well as our insight pieces. If there are topics you'd like us to cover, please visit our TechWatch page and submit a request. This is also where you can subscribe to receive future editions of TechWatch automatically.

In this issue, we take a look at people and how technology can affect our performance and protection in complex hostile environments. Then, at the other extreme, we look at robotics and autonomous systems with a review of the latest technology on the horizon. We also assess how emerging technology is creating new ways for humans and machines to team.

We hope you enjoy this inaugural edition.

MIKE SEWART
Director of Research, Experimentation and Innovation at QinetiQ

In this issue



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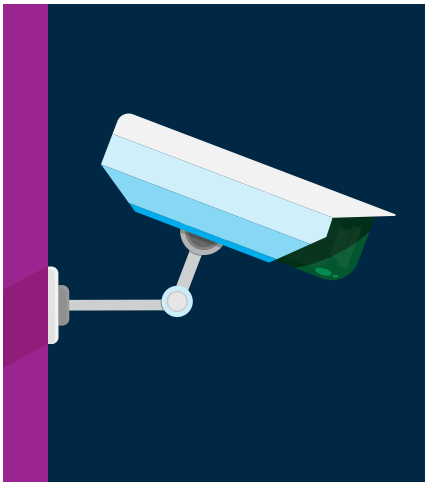
Cover: Bell Nexus. Credit: Bell Textron Inc.

NEWS



A new Chinese camera can photograph you from 28 miles away

Chinese researchers have developed a lidar-based system that can cut through city smog to resolve human-sized features at vast distances.

Their technique uses single-photon detectors combined with a unique computational imaging algorithm that achieves super-high-resolution images by knitting together the sparsest of data points.

It's based on the laser ranging and detection capability of lidar. This technology illuminates a subject with laser light, creating an image from the reflected light.

This technology has obvious military application in the Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) domain.

SOURCE:	MIT Technology Review, 3 May 2019.
RELEVANT TO:	Sensing, Processing and Data Fusion.

ESTIMATED TIME TO MATURITY:
0 to 2 years.

Israeli start-up claims to have a radar chip that can see 'through' cars

Vayyar, an Israeli start-up, claim they have developed technology that makes it possible to see through objects.

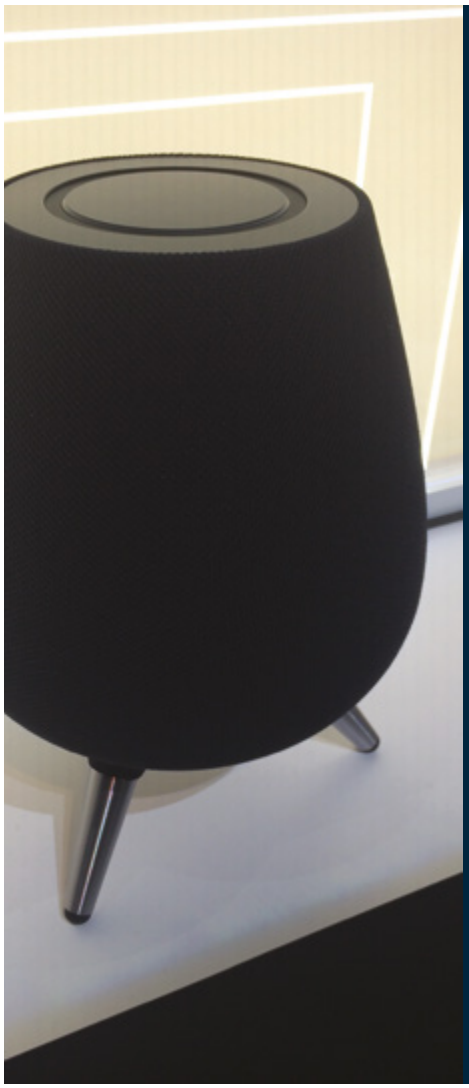
Their so-called 'Radar on a Chip' (ROC) was initially envisioned for the automotive industry and autonomous vehicles. The chip constructs a real-time, high-resolution 4D point cloud visualisation. This enables in-cabin passenger location and classification - analysing occupant size, vital signs and posture. It also builds a 360° map of the vehicle's exterior.

The company believe that radar, when implemented on a chip, currently offers a more cost-effective approach than lidar, and is capable of delivering a high degree of autonomous driving on its own.

Interestingly, the sensing of objects inside and outside the vehicle is entirely through radar. This technology could clearly be useful for military applications when coupled with other sensors (such as cameras) and an appropriate data fusion engine.

SOURCE:	Vayyar, EETimes 11 June 2019.
RELEVANT TO:	Robotics and Autonomous Systems. Sensing, Processing and Data Fusion.

ESTIMATED TIME TO MATURITY:
0 to 2 years.



Full conversation becomes a possibility, as 'smarter' virtual assistants draw near

When the concept of voice-activated virtual assistants first came to light (see Apple's 'Knowledge Navigator' for example) the idea of voice-activated AI was a hopeful pipe dream. Now it's rare to find someone who hasn't heard of Amazon's Alexa, Google's Assistant, Apple's Siri or even Samsung's Bixby.

A recent article from CNET provides some insight into what the consumer can expect over the coming months, as voice assistant technology (and its market share) march forward.

For example, both Alexa and Google Assistant require a 'wake word' or phrase to initiate nearly every new line of conversation. Now both Amazon and Google are planning to reduce the need for these wake words, allowing the conversation to flow more 'naturally'. Siri is following in a similar vein, but lags behind the market leaders.

Although the technology is still a long way off from the idea originally envisioned in Knowledge Navigator, more seamless conversations that enable you to do more with your device appear to be around the corner.

The technology certainly offers potential for military applications. For example, next generation virtual assistants could support a user in digital-based tasks, acting as a smart advisor offering timely guidance to support military decision-making.

As a final word, we must remember that voice activated assistants are still in their infancy. Both conversational/contextual technologies (…as well as a host of privacy concerns) must be addressed before users will be comfortable 'conversing' with their devices.

SOURCE:	CNET, 7 June 2019.
RELEVANT TO:	AI, Analytics and Advanced Computing.

ESTIMATED TIME TO MATURITY:
2 to 5 years.

Smallest pixels ever created open the door to active camouflage technology

Researchers at Cambridge University have succeeded in creating the smallest pixel ever designed for a visual display. It's about a million times smaller than the pixels currently used in smartphones.

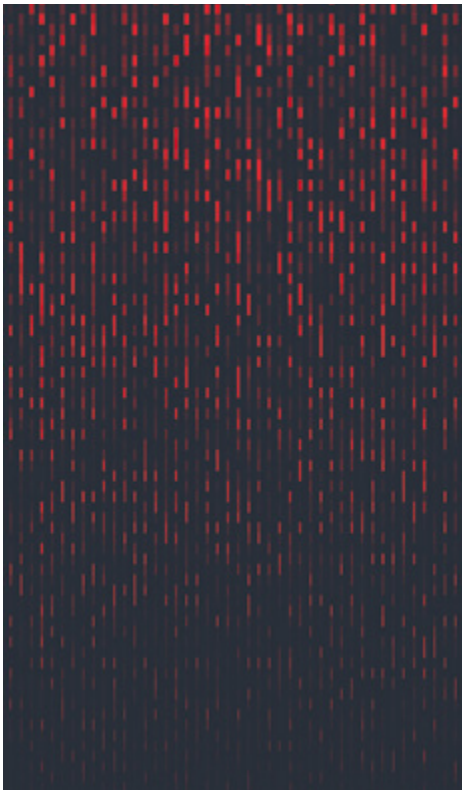
The innovation at the heart of this new technology? Grains of gold a few nanometres across (for reference, a nanometer is 1,000,000,000th of a metre).

Whilst novel due to their size, these new pixels are also easy to make and can be manufactured within large-scale plastic films at low cost. This makes them ideal for large, flexible displays.

It's easy to envisage a host of applications for this technology, in defence. One can imagine the films being used to create active camouflage clothing and coatings that can be applied to buildings, vehicles and other platforms - giving them a chameleon-like ability.

SOURCE:	University of Cambridge, 10 May 2019.
RELEVANT TO:	Advanced Materials and Manufacturing. Human Protection and Performance.

ESTIMATED TIME TO MATURITY:
2 to 5 years.



NEWS

A wearable device that can read your emotions may soon be available

Recent news suggests that Amazon is developing a voice-activated wearable device that can recognise human emotions.

Research and development relating to emotion detection and recognition has been ongoing for some time, but the likes of Amazon getting involved could be a major tipping point.

Emotions are intricately linked to functions such as attention, memory and decision making. As such, there's a lot to be gained by treating emotional state as an additional input in human computer interfaces. There are many potential military applications for such technology, from using it in training environments to employing it in vehicles. The automotive industry is already developing the technology, enabling vehicle cabin's to adapt or respond to driver emotional state.

The Amazon device is said to be a wrist wearable, designed to work with a smartphone app. It's able to detect the user's emotional state from the sound of their voice.

Besides Amazon, a number of smaller start-ups (such as Affectiva) are working on similar variations of this technology. As an alternative to voice, 'facial coding' (the process of measuring human emotions through facial expressions) is another conduit through which companies use AI to understand how people feel.

Some reports indicate that the broader emotion detection and recognition market was worth around $12 billion in 2018 - and could grow to more than $90 billion by 2024.

SOURCE: Bloomberg, 23 May 2019.

RELEVANT TO: Human Protection and Performance.

ESTIMATED TIME TO MATURITY:
2 to 5 years.

Handy new technology may allow robots to 'feel'

Until now, robotic and autonomous systems primarily relied on vision and language to gather information about their environment.

Now, a team of researchers from the US Massachusetts Institute of Technology (MIT) have developed a 'tactile glove' that could ultimately provide machines with a 'sense' of touch, such that they could also 'feel' the world around them.

This glove is packed with pressure sensors, enabling the team to compile the largest-ever collection of tactile data, relating to different human grasps for up to 26 different objects. This tactile data is then used to train machine learning algorithms to identify the objects from touch alone.

This research is expected to aid the development of robot grasping tools, improve human-robot interactions and support a host of other applications that will eventually include many robotic and autonomous systems serving the military. Interestingly, the materials used to make this glove only cost about $10.

SOURCE: MIT News, Nature, 29 May 2019.

RELEVANT TO: Robotics and Autonomous Systems.

ESTIMATED TIME TO MATURITY:
2 to 5 years.

The dawn of drone based quantum communication networks

A recent paper from researchers at Nanjing University in China explores the use of drones acting as 'airborne nodes' to create a low cost, local quantum communication network.

Using quantum entanglement to create secure communications systems is not a new concept. The ability to conduct such communications with the desirable property that any interception or eavesdropping over the channel would be detectable would be extremely useful to the military.

There already exist a number of experimental quantum networks that use satellites as nodes. However this approach has some drawbacks - satellites are usually expensive and can only establish data links within defined transmission windows. Additionally, over long distances there is an increased incidence of photon loss, which degrades the communication channel.

The drone network will overcome these obstacles by allowing for the creation of ad-hoc networks that can interoperate with existing infrastructure, such as satellites and ground fibre-based systems.

Additionally, 'cascaded transmission' (dividing a long link into several shorter ones using multiple, interim drone nodes) will help to avoid photon loss over long distances.

The experiment demonstrated a system that can operate for up to 40 minutes at a time - providing two air-to-ground links situated 100m apart.

Planned follow up work includes refining the quantum communications payload to be smaller and lighter, and extending the concept to high altitude unmanned air vehicles (UAVs), which would offer greater link distance.

SOURCE: IEEE Spectrum, 18 June 2019

RELEVANT TO: AI, Analytics and Advanced Computing.
Secure Comms and Navigation Systems..

ESTIMATED TIME TO MATURITY:
2 to 5 years.

New kinetic energy capture tech achieves success - in a sandal

'Energy harvesting devices' can capture energy from external sources. One such source of energy is the kinetic force we can derive from movement.

Harvesting energy from motion isn't new, but a material created by researchers at Rice University in the US may make the process more practical - particularly for use in wearable electronic devices.

The researchers have found that when laser-induced graphene ('LIG') composites are put in contact with other surfaces, static electricity is produced in a similar manner to that of rubbing a balloon against hair. This is known as the 'triboelectric effect', where materials gather charge through contact.

As an example, the team embedded LIG in a flip-flop which, through repeated contact with the user's skin, enabled them to generate energy with every step. To quote one of the researchers: "The nano-generator embedded within a flip-flop was able to store 0.22 milli-joules of electrical energy on a capacitor after a 1-kilometre walk."

Whilst 0.22mJ of energy might not be much, if you consider the number of shoes in motion at any one time, there's a lot of potential here.

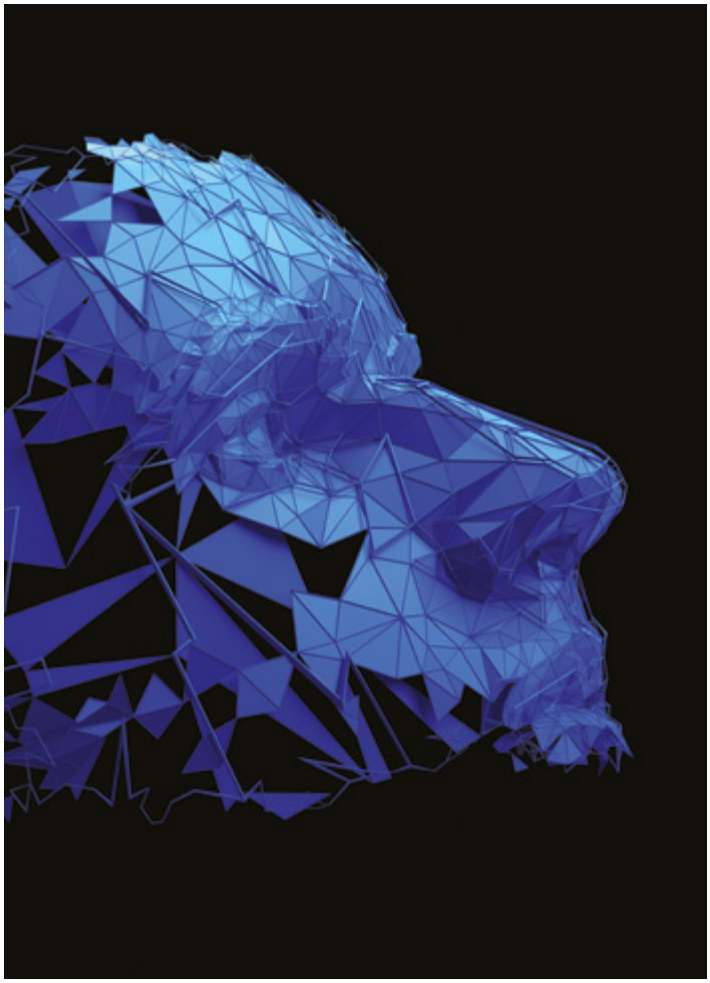
Such technology is clearly constrained to small devices or sensors, but one could easily imagine it being incorporated into clothing, as well as footwear. In terms of application to the military - any innovation, such as this, that could improve a dismounted soldier's Size, Weight and Power (SWaP) profile has to be a good thing.

SOURCE: Rice University, 31 May 2019.

RELEVANT TO: Advanced Materials and Manufacturing

ESTIMATED TIME TO MATURITY:
2 to 5 years.

NEWS



Facial recognition from DNA becomes available

A team of Belgian and American engineers have built a database-scanning algorithm which can link faces to DNA found at a crime scene.

Linking a specific human face to the individual's DNA remains a challenge and is still very much the stuff of science fiction. The truth is that the shape of our face is not just determined by thousands of genes, but also by our diet, age, environment, and socioeconomic background.

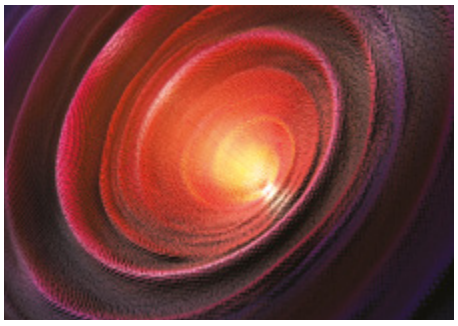
However, researchers have brought such a possibility closer by devising a method that provides a range of possible reference faces from a DNA sample - making it possible to rule people out, at least.

So whilst they may not have uncovered the holy grail for crime-fighting, they have built a powerful tool which will become more accurate as more genes are identified. Hold on to your privacy (while you can).

SOURCE:	KU Leuven, Nature Communications 11 June 2019.
RELEVANT TO:	AI, Analytics and Advanced Computing.

ESTIMATED TIME TO MATURITY:
5 to 10 years.

Stanford researchers work out how to 'see' around corners using sound



Researchers from Stanford University have developed a novel (and relatively cheap) approach to 'seeing around' corners.

Until now, the detection of objects in such circumstances has used complex optical systems with highly-sensitive, time-resolved photo detectors and ultra-fast pulsed lasers.

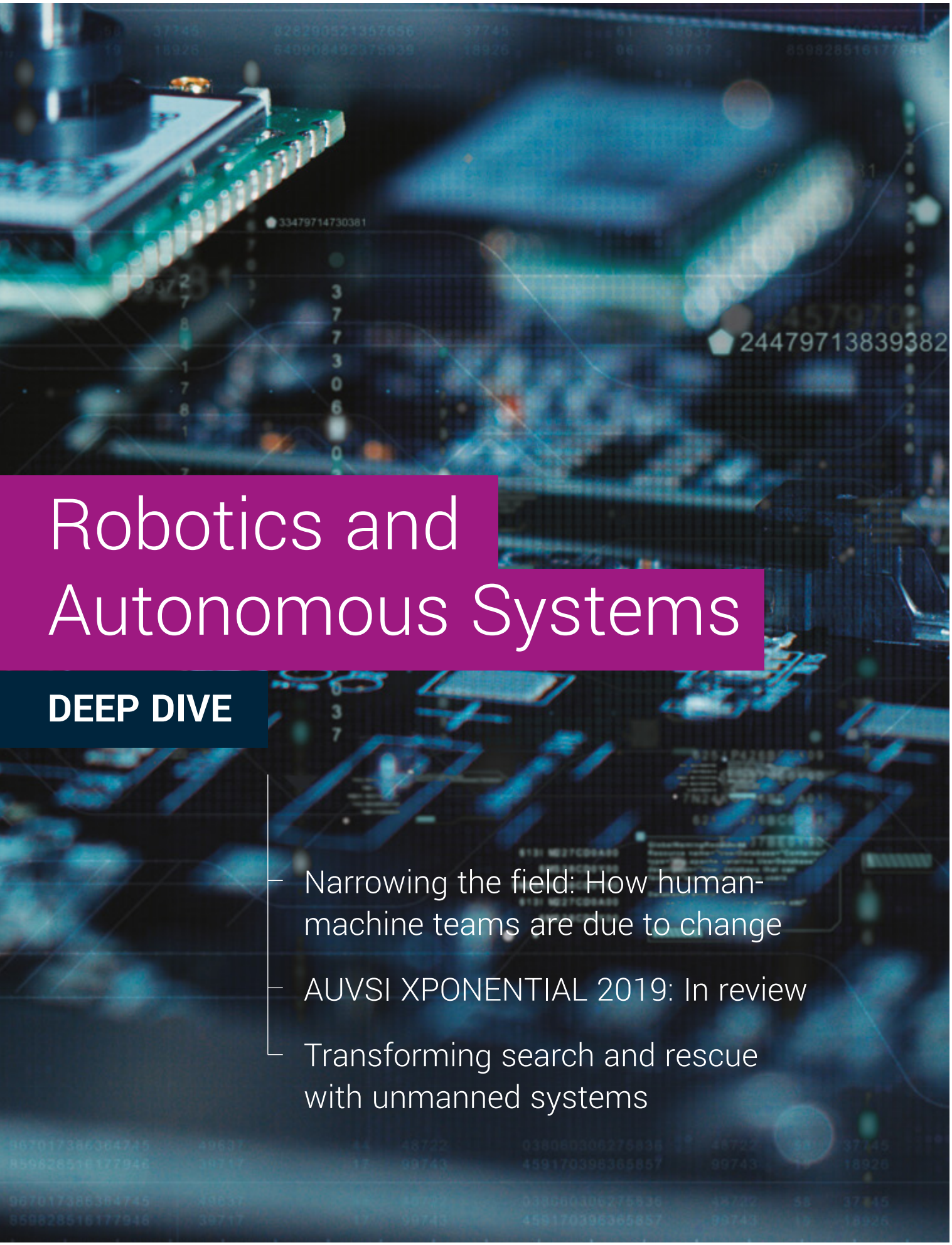
Their new technique uses acoustic echoes instead. The process involves a vertical pole equipped with off-the-shelf microphones and small car speakers.

This rig is moved in small increments and each time the speakers are made to emit a series of chirps. These bounce off a nearby wall at an angle before hitting a hidden object behind an occluding screen. The microphones capture the timing of the returning echoes and reconstruction algorithms are used to recover the geometry of the hidden object.

The researchers point out that their technique is considerably cheaper than the optical alternative. One of the applications that they have in mind for the technology would be for autonomous vehicles to detect unseen obstacles. It could also be used for mobile robots.

SOURCE:	Stanford Computational Imaging Lab., June 2019.
RELEVANT TO:	Sensing, Processing and Data Fusion. Robotics and Autonomous Systems.

ESTIMATED TIME TO MATURITY:
5 to 10 years.



Robotics and Autonomous Systems

DEEP DIVE

ROBOTICS AND AUTONOMOUS SYSTEMS **DEEP DIVE**

Narrowing the field: How human-machine teams are due to change

Computers are being given more specific tasks to automate and more complex algorithms to work with. This is stimulating a change in the balance of human-machine teams.

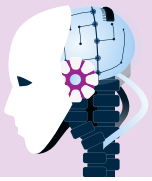
The recent Army Warfighting Experiment and the early demonstrations as part of NavyX have demonstrated a vision of our immediate future. They were both characterised by a diverse range of unmanned vehicles and systems, some powered by artificial intelligence (AI), successfully collaborating. Important as it was to deliver a demonstration of integrated autonomy in action, it was also clear that humans and machines need to work as a team to enable success. The question is how that finely balanced relationship may change as technology gets smarter and ever more autonomous?

Some decisions must always be made by humans. Those requiring the use of lethal force, for example, should always have tight human control and a person at the centre of the decision loop. As good as AI already is, every environment in which it needs to operate could be very different and humans are currently able to make faster, more accurate judgements in new environments than computers, which are bounded by defined goals or timeframes and the training and test data used in system development. But a series of new technologies and approaches are closing the gap.

Narrow AI

One of the most notable changes is that the jobs AI systems are being given are starting to become more specific. We are witnessing more instances where AI is being trained to handle very particular tasks around better-defined targets.

Termed 'Narrow AI' this increase in specificity is making the output of AI's work much more relevant to the needs of the user. It is also changing the human role to one of trainer and decision maker, enabling an increase in the amount of delegation to automated systems. With much tighter parameters, AI can do more of the legwork on discrete projects without having to accommodate a huge spread of data. It can become more focused, faster, and provide richer context for human decisions.



Edge processing

One of the factors enabling the move to Narrow AI is an increase in the amount of data processing and analysis that can take place at the point of capture, reducing the need for a separation of AI and sensing technology. Much of what sensors beam back to users is of limited value because the subject in question might be surrounded by lots of irrelevant information. Distributing this and sifting through it uses up a lot of bandwidth and communications capacity. With AI starting to be built into sensors themselves, the information flowing back to users is no longer raw data but richer, sifted intelligence from which decisions can be made far more quickly. A good example emerging onto the market is Anduril's Lattice Sensing Tower, which integrates AI into a sensor array including night vision, RADAR, and optical imaging. It allows the tower to both identify and classify targets automatically, effectively filtering the data it sends to security professionals so they can act almost immediately.

KP Labs, based in Poland, is building a new satellite that will do something similar but in space. Intuition-1 will be launched in 2022. It is controlled by a neural network and is equipped with a hyperspectral imager – a highly advanced camera that will take 150 different photos of every scene it looks at. Each picture is at a different spectral frequency so it contains different information. The neural network stiches them all together but instead of sending back all the information contained in the images, it will identify only those elements that the user has told it will be useful. This will massively reduce the data load on transmissions back to earth and therefore speed up the process of receiving, reviewing and acting upon it.

Smarter sensors

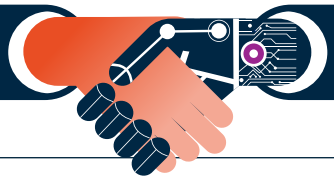
The tech trend applying Narrow AI to edge processing is being accelerated by the development of smarter, richer but lower cost sensors. As technology companies have realised that more computation is starting to take place before data reaches an operator they are pre-empting a notable shift in the human-machine teaming balance by building more capable sensors. nVidia – the world leader in graphics chipsets for powerful computing systems has recently announced its nVidia Drive AGX – a graphics-based platform on which to build autonomous vehicles that can read their surroundings through a combination of advanced optical processing, graphical modelling, and AI underpinnings. This level of sensor technology is not reserved for building the cars of the future. We are starting to see it as standard on many existing air, land and sea vehicles. The latest Unmanned Air Vehicles (UAVs) demonstrate a generational shift in out-of-the-box sensor performance. The quality of their sensing technology is far higher, leading to much better quality video; advanced stabilisation; improved imaging tracking; and both obstacle avoidance and auto height keeping as standard. These are not new sensing capabilities but they are only now starting be pre-packaged elements on modern, increasingly military-grade UAVs.

The next phase of sensing improvements that will accelerate the move to Narrow AI and offer even greater utility for autonomous systems will come from quantum technology. The benefit of quantum is that it brings with it heightened sensor performance through the ability to measure very sensitive changes in the environment at almost 10 times the speed of today's equipment. It does this by taking advantage of the fact that atoms are wave-like in their behaviour. That means that you are able to use each atom as a very accurate ruler, against which to measure certain things, such as changes in the earth's gravitational or magnetic fields. Doing so enables quantum sensors to accurately identify submerged activity such as insurgents moving through underground tunnels, or the presence of enemy bunkers, which are beyond the scope of traditional optical equipment. Several companies around the world are working together to develop quantum sensors. They include NASA, the University of Birmingham, the University of Oxford, the University of Strathclyde, QinetiQ, Altran, and Teledyne e2V. The Gravity Pioneer Project is one of the most recent additions to the market – utilising £6m of UK funding to build and test a new quantum gravity instrument for use in multiple defence, security and critical infrastructure environments within the next few years.

Rebalancing the equation

These technical developments are stimulating redefinition of the balance in human-machine teams. Current research is focusing on giving users a greater ability to fine-tune the levels of autonomy and delegation for individual tasks based on mission complexity, operator experience, environmental circumstance, and technology capability. This adaptability is an essential part of establishing a more accurate and effective human-machine team dynamic and a more flexible way to scale up and down the amount of AI delegation for different missions. Increasingly this adaption will be automated, albeit supervised. As a result, the role of the human is shifting slightly further away from the task itself – to 'trainer' at the outset, and 'decision maker' at the close. AI is starting to enjoy increased task delegation, based on the increasing performance of sensors, the speed at which they can operate, and the trust we can place on them.

As modern combat evolves, the evolution of underpinning technologies and systems can potentially reshape the structure of human-machine teams as part of the challenge to maintain combat mass and effectiveness at the point of conflict. Being acutely aware of the respective technology roadmaps would be one way to predict how these team structures might need to evolve over the next 5-10 years.



ROBOTICS AND AUTONOMOUS SYSTEMS **DEEP DIVE**

Bell Nexus. Credit: Bell Textron Inc.

AUVSI XPONENTIAL 2019: In Review

The scale of Chicago's 'XPONENTIAL' trade show, hosted in the spring by the Association for Unmanned Vehicle Systems International (AUVSI), is testament to the explosion of interest in robotics and autonomy.

With 700 companies competing for the attention of 8,500 attendees, pinpointing Xponential's standout technology trends was always going to be tricky. Thankfully, Phil Briggs, a thought leader for UAS in QinetiQ, was up to the task.

Personal air transportation: not a pipe dream anymore

While we tend to consider driverless cars the 'next big thing', pilotless personal air transportation is still seen as a distant pipe dream. But Xponential demonstrated that the 'urban air mobility' concept is quietly gaining momentum, and its realisation may not be as far off as we think.

Bell Helicopters' 'Nexus' – an 'optionally piloted' air taxi the size of a minibus – was one of the exhibition's major head-turners. Visitors may have been familiar with smaller unmanned passenger air vehicles, such as those being developed by Malloy, Volocopter and Ehang, but what made the Nexus stand out was its sheer size.

Although in the concept phase, it is predicted to have a top speed of 150 mph with a range of 150 miles, thanks to its hybrid gas-electric motors. Urban air mobility has been identified as an area of interest by other large manufacturers, including Airbus and Boeing - the latter has two variants currently in flight test.

The technologies currently being developed by these companies in the civil space will soon prove invaluable in defence. In 2018, a team led by QinetiQ demonstrated the potential for unmanned ground and air vehicles to work together in delivering humanitarian aid to the front line, as part of Defence Science and Technology Laboratory (Dstl) 'Last Mile Autonomous Resupply' exercise.

By integrating larger vehicles like the Nexus into this infrastructure, the mission scope can be extended to include casualty evacuation and heavy cargo drops, keeping personnel out of danger. It will also free up pilots to operate the aircraft's systems, enabling them to place more focus on missions.

SLAM: the greatest thing since GPS

The march towards a driverless road network continues, led by several exhibitors that have been granted licenses by the State of California to operate unmanned cars and trucks.

Among these was TuSimple, which shared videos of trucks modified with its equipment conducting 90-minute drives on roads and interstates with no operator intervention at all.

But beyond the audacious showpieces was a rather more subtle (yet no less interesting) low-speed autonomous car demo. Visitors could ride in a Tesla vehicle fitted with a product by Artisense that enabled it to navigate without satellites.

The product, which Artisense calls a 'visual inertial reference system,' employs simultaneous localisation and mapping ('SLAM') techniques to determine a route from a map, then update the map as it encounters obstacles.

Artisense claims to offer the only navigation system that's not dependent on GPS or other satellite networks, allowing it to navigate in tunnels and underground garages, as well as out on the open road. In fact, QinetiQ's 'Titan' ground robot has previously demonstrated this capability off road, using a camera-based navigation system developed by Aberystwyth University.

The ability to navigate without GNSS will be critical to the deployment of autonomous systems in a defence context, as conflict often takes place in environments with little or no access to GNSS, either due to poor local infrastructure or deliberate denial of service.

Swarm tactics, formation flying and drone wingmen

The US Naval Research Laboratory exhibited its 'Close-In Covert Autonomous Disposable Aircraft' ('CICADA') concept. These miniature aircraft can be released in swarms from aircraft, UAVs or Sonobuoy canisters, before gliding to within five metres of a specified location.

These could be used to deploy a wide-area battlefield sensing system or radio network, with the CICADA's many constituent parts making the system very hard for an enemy to disable.

DARPA Cicada

The aircraft can be mass produced by robots to minimise production costs, and can be stacked together to enable high packing density for ease of transportation. They may be particularly useful in enabling unmanned ground vehicles to manoeuvre in new unknown environments.

Meanwhile, Airbus was keen to show off its concept for a low-cost unmanned 'wingman' operating alongside a Typhoon fast jet. There are no firm plans to do anything with the concept but they suggested it was something they were investigating. This and similar US, UK and Australian projects could spark an evolution in aerial target technologies, making them more cost effective – much like Kratos has done with its UTAP-22 Mako 'loyal wingman'.

Airbus Remote Carrier

Rotary wing or fixed wing? Why not both?

Choosing between a rotary-wing and a fixed-wing unmanned air system (UAS) inevitably involves compromise. A quadcopter-style aircraft offers precision control, plus vertical take-off and landing (VTOL), but at the expense of battery life and therefore range. A winged aircraft can travel greater distances at speed, but requires a runway or launcher to get airborne, and must maintain constant forward momentum to stay in flight.

Users understandably want aircraft that offer the best of both worlds, so manufacturers are responding with innovative designs that negate the need to choose. In the defence world, the fixed-wing compromise may sound familiar to users of Boeing's ScanEagle UAV. While excellent at conducting surveillance missions, its launch and recovery system has not exactly been met with universal acclaim.

This has led Northwest UAV to create a multi-rotor attachment that can launch and recover the ScanEagle in the air, helping to answer critics who point to the limited space available for ship-borne use.

Elsewhere, Californian company PteroDynamics exhibited what I believe to be the most elegant hybrid air vehicle design I've seen in a long time. Its 'Transwing' design enables the vehicle to take off vertically before transforming mid-air into a propeller-driven fixed-wing aeroplane.

Describing the concept doesn't do it justice, so we urge you to check out the company's videos.

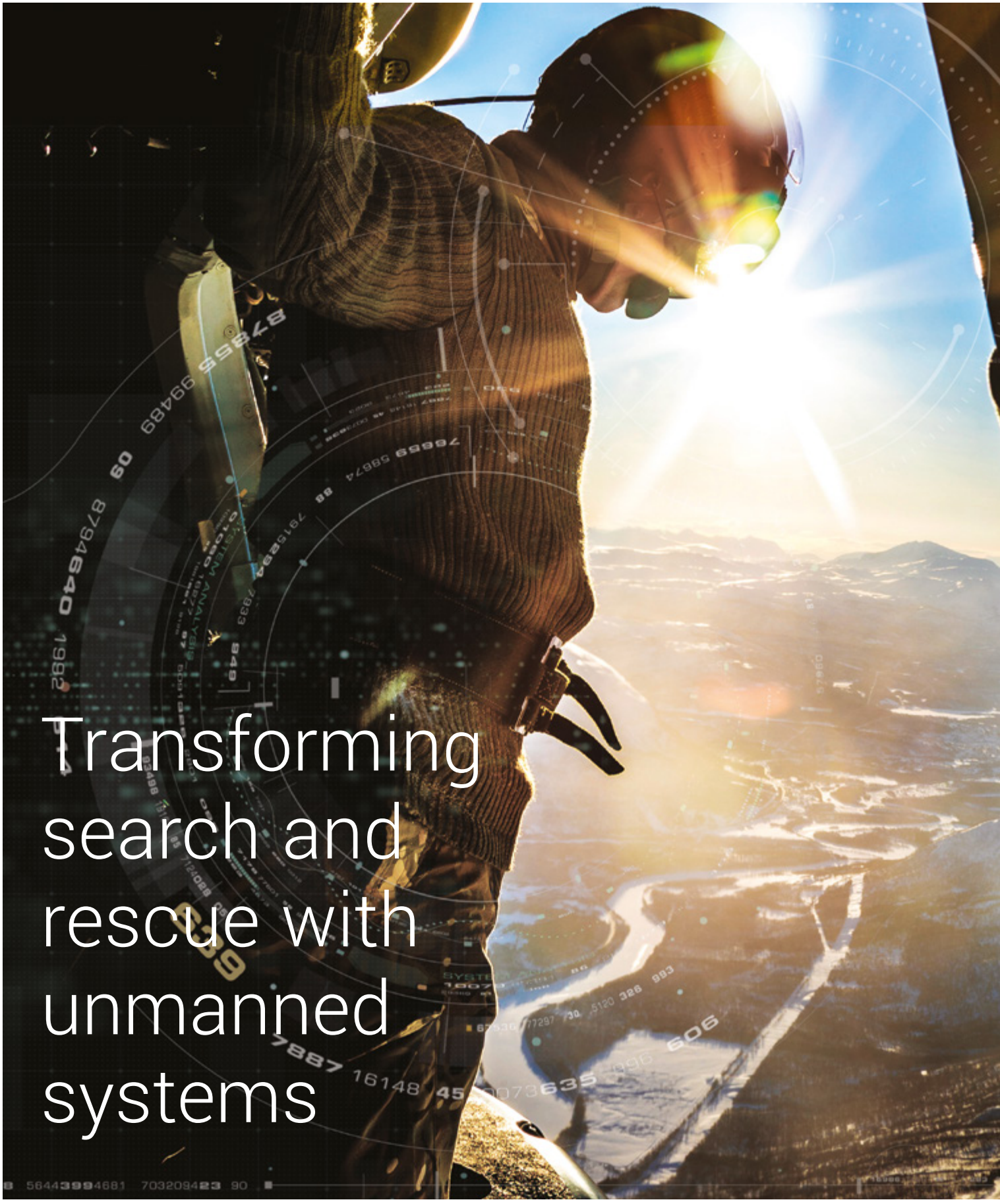
Conclusion: legislation (not technology) will be the last hurdle

Xponential demonstrates that the technologies needed to enable autonomous transportation (whether on the ground or in the air) are progressing faster than many thought possible.

In fact, technological barriers are being knocked down so quickly that it's actually regulation, not technology, that is most likely to constrain future progress.

So, why do companies like those at Xponential continue to develop and promote their tech, knowing that it can't legally be used?

The answer is simple. As various groups work to address the legal issues, the holy grail for any autonomous transportation manufacturer is for its vehicle to be the one that legislators write the regulations about.



Transforming search and rescue with unmanned systems

Barely a day goes by without a company announcing it has found a quirky new use for its drone – whether it's cleaning windows or delivering a pizza. While some of these new uses are little more than publicity stunts, others – such as transporting donated organs for use in surgery – may be genuinely lifesaving. But no matter how innovative the application, a single drone will never truly revolutionise the way an organisation operates. So yes, it's possible to do some pretty neat things with a drone. But for QinetiQ's UAS thought leader Phil Briggs, a solitary unmanned platform is no longer enough.

QinetiQ's Unmanned Systems team recently had the pleasure of collaborating with the Maritime and Coastguard Agency (MCA), which oversees search and rescue operations in UK waters. The MCA's volunteer Coastguard Rescue Teams are heroes, routinely risking their own lives to save those of others. All parties have a shared interest in ensuring these volunteers return home safely at the end of each shift, so we've been looking at how unmanned systems can help them perform their duties with less risk.

It's no longer enough to own a lone drone

On the face of it, the solution may seem obvious: fit a quadcopter with a camera and GPS tracker, train a team member to pilot it, and send it up to look for those in need of rescue. While this approach has proven effective in certain situations, to use an isolated unmanned system in this way is to seriously underutilise its full potential.

This is what we sought to demonstrate with the MCA. When their rescue teams receive a call, they need to locate the person in distress, intervene to ensure their immediate wellbeing, and recover them to a safe location. This goes well beyond what can be achieved using raw data provided by a single drone or group of drones. If a mission was conducted using four drones operating independently, four volunteers would be focused on flying them. Each would be reporting back to the commander, who would have to collate and interpret data from four disparate sources.

A fast, effective response demands actionable information that supports informed decision making without adding more tasks to the team's overall workload. Our demonstration allowed MCA control room staff in the National Maritime Operations Centre, Fareham, to control the sensor of an unmanned system in flight at Llanbedr airfield in North West Wales – over 200 miles away. The live situational awareness feed, including search status and reference points, was distributed to multiple teams; at the search site in Llanbedr, and to remote sites in Fareham, London and Southampton. Meanwhile, search teams on the ground were equipped with rugged tablets with moving maps, sensor feeds from the air systems, and search progress information, enabled by a network that shared voice and data among all participants.

The ultimate aim here is to move away from a scenario in which multiple people operate and receive data from multiple drones, to one in which a single person operates multiple drones that collaborate to provide everyone with a single, consistent picture of the whole situation.

Aiming higher

The successful MCA exercise is a microcosm of a future society in which networked unmanned systems are capable of transforming search and rescue on a nationwide scale – and it need not be limited to a single organisation like the MCA. Numerous other public bodies have surveillance requirements, such as police forces searching for missing persons and suspects on the run, or the Environment Agency monitoring emergencies such as flooding or water contamination. Each of these bodies reports into a different government department: the MCA into the Department for Transport; the police service into the Home Office; and the Environment Agency into the Department for Environment, Food & Rural Affairs. Each of these may wish to develop its own unmanned surveillance capability – but the bigger opportunity lies beyond individual governmental silos. Just as it's more effective for a single agency to implement an infrastructure that supports multiple unmanned systems, it will be more effective – and cost efficient – for government to implement an infrastructure that supports multiple agencies.

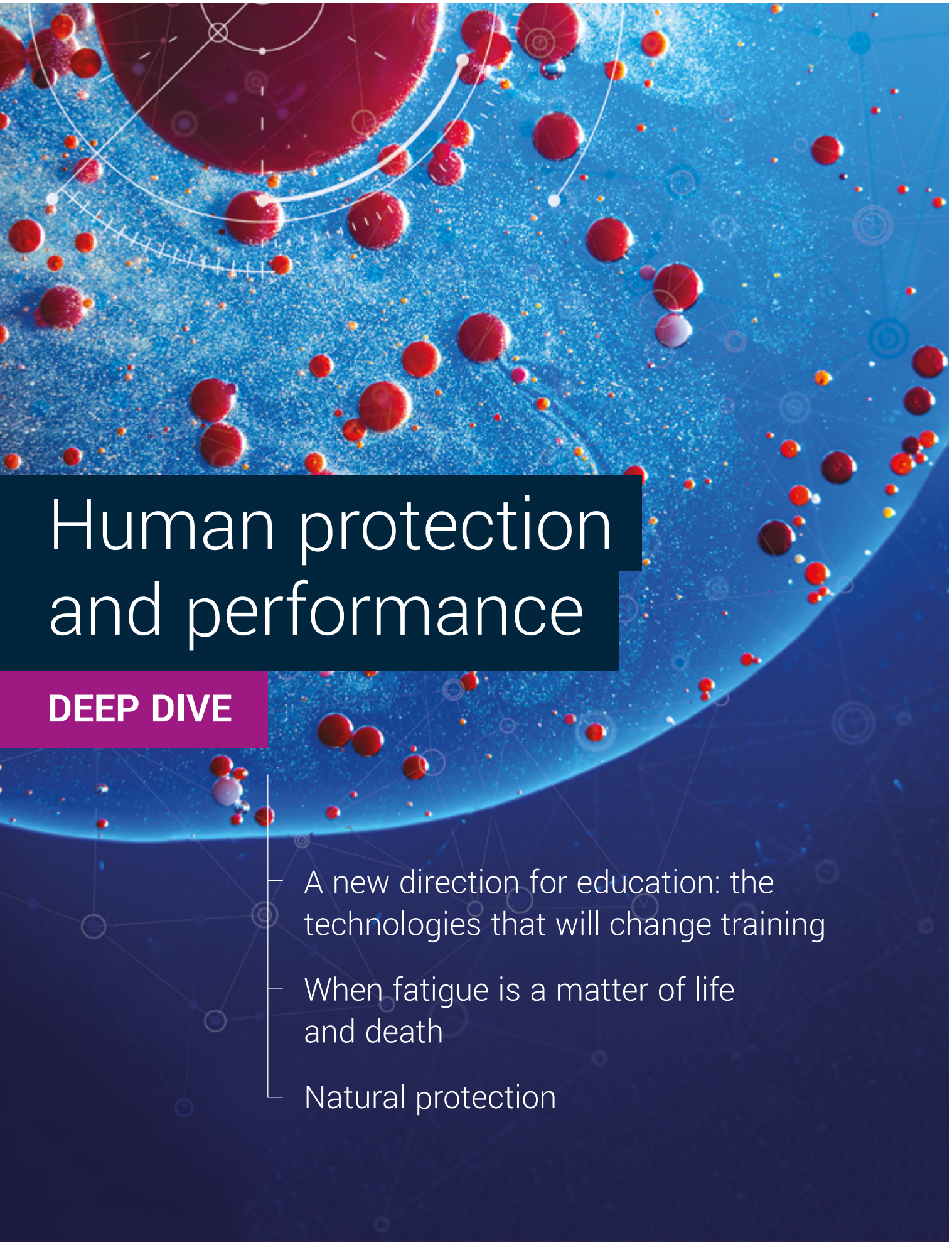
A federated model for unmanned search and rescue

Future search and rescue operations will be conducted by multiple agencies via access to a national information service managed at a government level. All agencies with manned or unmanned search and rescue assets will feed data into the centralised system, which will prioritise and interpret it before redistributing it to the relevant parties in the form of decision-ready information. Operating across silos will reduce duplication of effort and offer a much more comprehensive situational awareness picture.

Exactly what this infrastructure will look like is open for discussion, but it will most likely be a cloud-based model not dissimilar to Amazon's web services. The data-gathering network will consist of a range of unmanned assets from multiple service providers – for instance: satellite services from the European Space Agency; high-altitude pseudo satellites manufactured by Airbus or maritime patrol aircraft produced by Boeing; and local plugin services from small and medium-sized enterprises. The data gathered from the various sources will be uploaded to the national cloud-based management system and processed. Service users will access the system on a subscription basis, where they can search for any information that may be relevant to their operation, such as the accessibility of a location, local weather conditions, or disruption to transport routes that will impact response times.

Conclusion

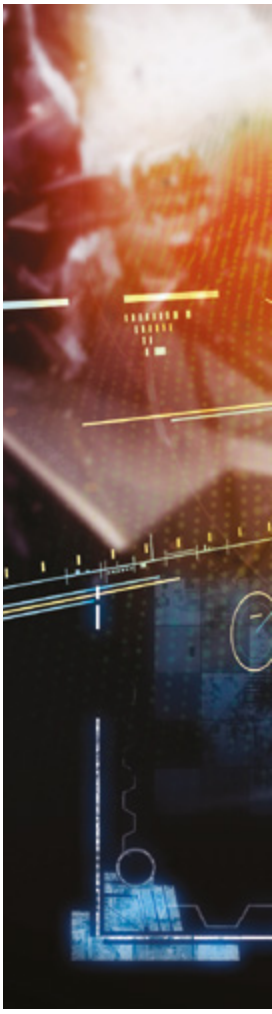
Search and rescue missions are an excellent match for unmanned systems. A drone is better suited to search tasks than a manned helicopter with technology aided search and at a lower operating cost. An unmanned maritime vehicle could approach a swimmer in distress and escort them back to shore. An unmanned ground vehicle could deliver aid to an injured hiker as they wait for weather conditions to clear, allowing recovery from the air. Any one of these technologies on its own may confer some small advantage, but recent advances in technology present huge opportunities to create a whole system that is bigger than the sum of its parts. If we stick to the simple tactics of the past, we will leave vast swathes of potential untapped.



Human protection and performance

DEEP DIVE

HUMAN PROTECTION AND PERFORMANCE **DEEP DIVE**



A new direction for education: the technologies that will change training

In the so-called 'Industrial Age', the teacher made the rules and the student followed them. But times have changed - and now the world of learning is starting to finally put the student at the heart of things.

This post-industrial, 'learner-centric' approach is the new common denominator in a range of upcoming powerful learning technologies. Helen Dudfield, Chief Scientist for QinetiQ's Training and Human Performance team, takes a critical look at the future of the training sphere…

A generational opportunity

Computer games are so much more than they used to be.

The tactical training environment once shaped the gaming world, but the tables are turning. Today, the military lags behind the likes of Fortnite and Minecraft – games in which hundreds (sometimes thousands) of players interact in immense, rich virtual spaces.

While the VBS3, one such training environment, has only been used by Ministry Of Defence (MOD) since 2016, it's unlikely to meet the expectations of the 'Digital Generation' - those who grew up on games of unrivalled complexity, and who are now coming into the workplace.

Ultimately, this new generation will demand more from their virtual training spaces, and some forward-thinking organisations are ready meet this need.

Enter Improbable, a $2 billion gaming start up that's changing the face of gaming. Not only can their SpatialOS platform support more players online than much of the competition, it also creates complex models of the real world - including real-time data from social media, utility systems and traffic.

The US Army has seen the writing on the wall, awarding Improbable a $5.8m training contract.

Training profiles vs the curriculum

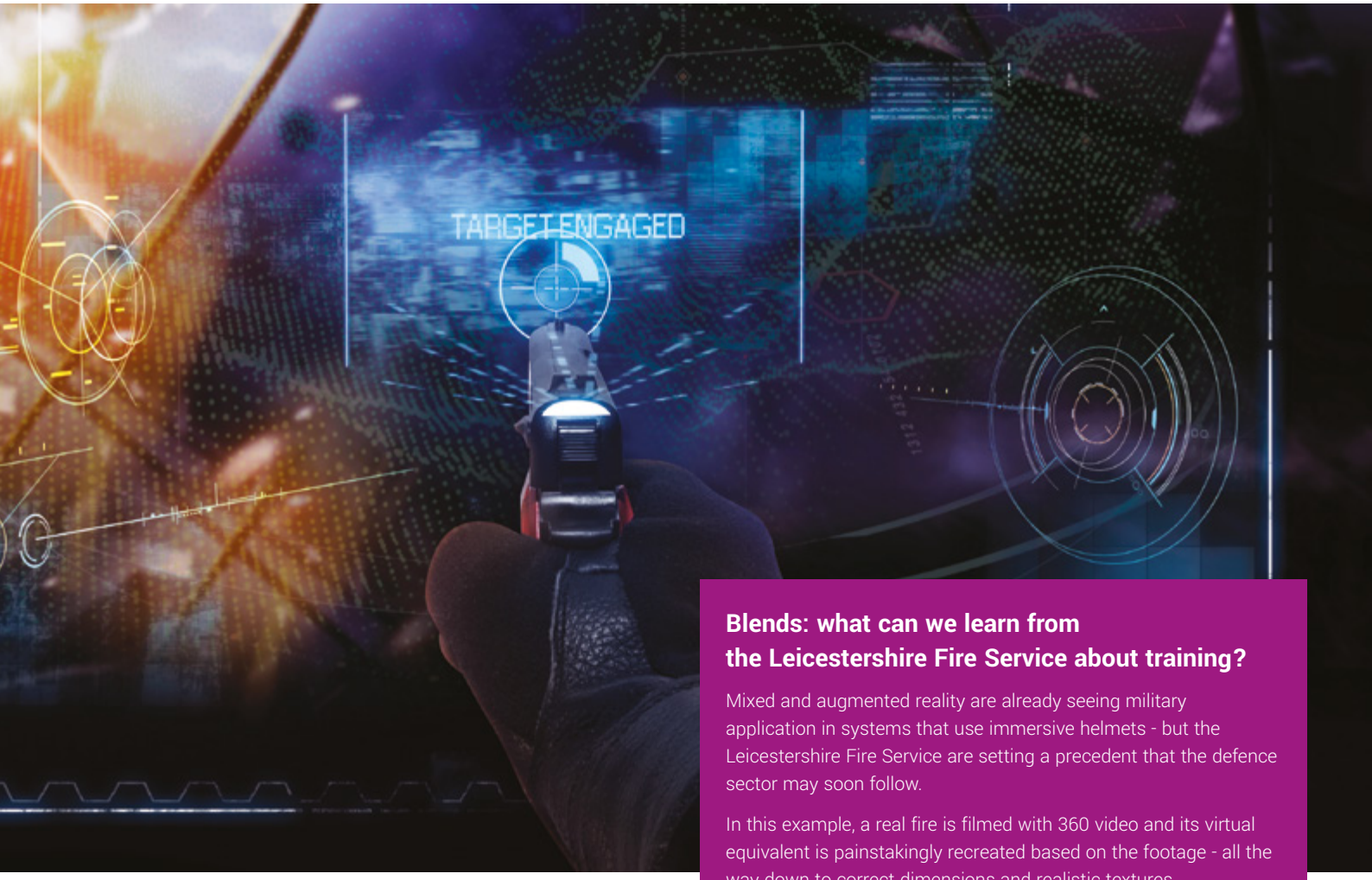
In the next 5-10 years we'll see the prescribed syllabus start to be replaced with machine learning that's driven by individual performance. There are a couple of layers to this: data analytics and adaptive learning.

Watershed is an example of the former. Currently in extensive use by the manufacturing industry and yet to be adopted in defence – Watershed is a system that collects training data, linking it to performance in the workplace. This builds a better understanding of how the most effective workers get to where they are.

For example, Watershed could help accurately gauge the results of a training course by monitoring the performance of all those who took it. In this way, a person's training record is captured, and can be carried through their career in a 'digital passport'.

Rather than an individual applying for a position, role matches can be put forward based on a candidate's existing skills and competencies. This could also prevent 'skill fade' - building models that predict exactly when skills need to be refreshed.

During training, adaptive learning uses artificial intelligence to track performance and choose the correct pace at which to progress - all without a trainer. Filtered is a personalised learning platform for the world's knowledge workers, and does exactly this. Royal Mail has begun work with Filtered and already seen positive changes in the workforce.



In a similar vein, CogBooks uses adaptive learning to match course content to the individual student.

By continuously adapting the duration and difficulty level, the experience is tailored to the learner's ability. Performance is recognised: the better you do, the faster your training progresses.

Many prefer the option to proceed at entirely their own pace - in fact, Royal Mail have seen a 24% increase in student success.

Mixed reality: when VR is not enough

As far as defence goes, Virtual Reality (VR) is now commonplace. It enables team members to train together whilst remaining geographically separate. Popular technologies like Immerse are a great example.

However, Augmented Reality (AR) and Mixed Reality (MR) are less prevalent - presenting the greatest near-term opportunity. Microsoft's HoloLens 2 has seen the largest investment from the US Army - quite possibly a sign of things to come.

This technology overlays the 'real world' with pop-ups as you move around, and once completed, there's the option to look back on the event and spot mistakes.

Rather than an expert needing to be physically present with the trainee, the HoloLens enables a live instructor to see the scene, draw on it, provide remote guidance and be accessible to the user.

Such physical attributes of augmented training are likely to become popular alongside VR within the forces.

Blends: what can we learn from the Leicestershire Fire Service about training?

Mixed and augmented reality are already seeing military application in systems that use immersive helmets - but the Leicestershire Fire Service are setting a precedent that the defence sector may soon follow.

In this example, a real fire is filmed with 360 video and its virtual equivalent is painstakingly recreated based on the footage - all the way down to correct dimensions and realistic textures.

The video the fire-fighters see is the real fire, but the scene in which they work is a replica. The same process could, quite obviously, benefit the military.

We'll likely see a shift towards 'blends' - training that uses a mix of live, virtual and constructive environments. This world will no longer require an expensive or sizeable physical simulator for the very physical effects required for proper training.

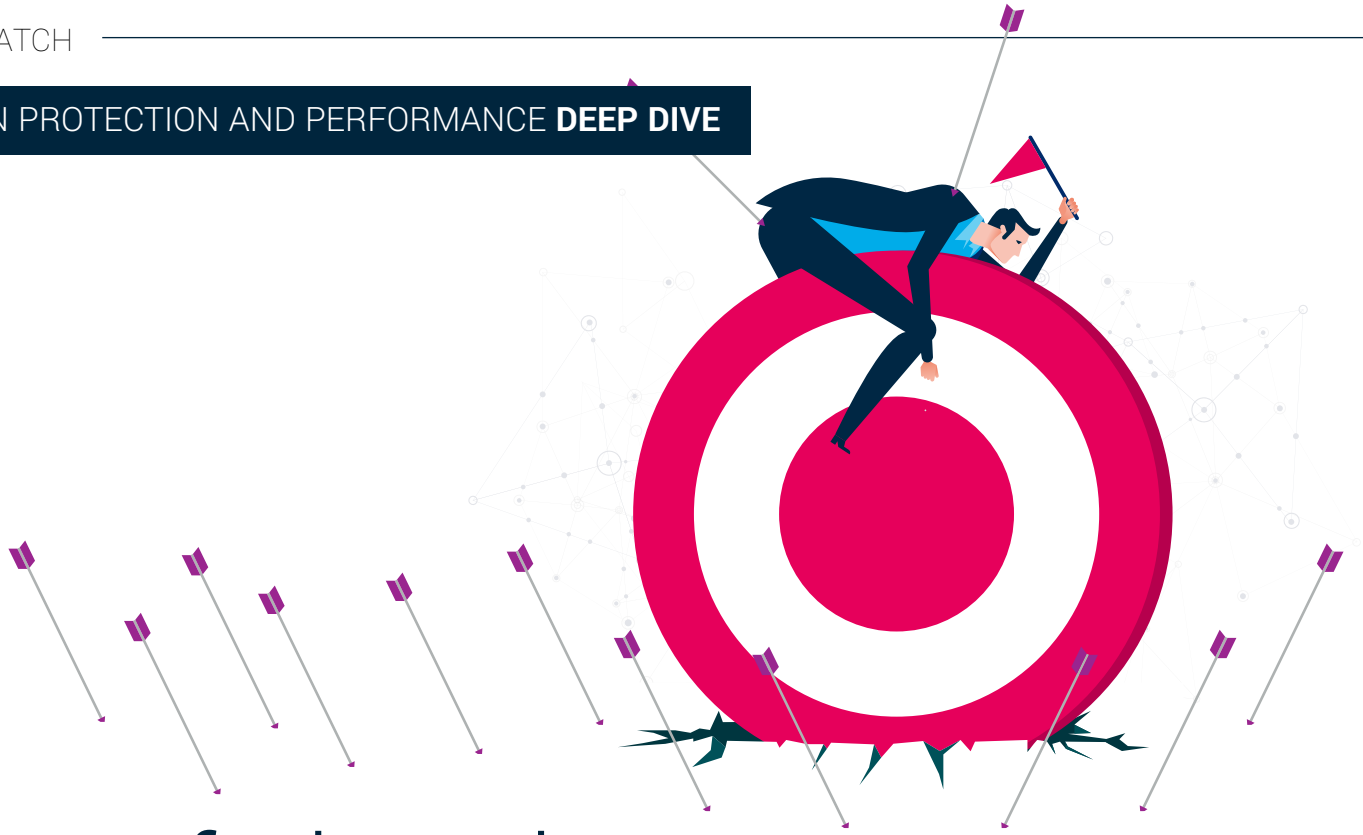
Next steps: "The best way to predict the future is to create it."

The Digital Generation have only ever known the post 'gamified' world. As such, the environment in which they train must match the complexities of the immersive commercial games that they grew up on.

This provides a greater opportunity to fuse 'the live' with 'the virtual', allowing more realistic mistakes and unsafe choices to be made in the environments in which we can afford to make them.

With 5G and Secure Cloud each supporting the growth of these technologies, the concept of a digital passport will allow for more effective training courses, alongside better-suited jobs - all at a completely individualised level.

Combine this with the chance to blend various kinds of virtual realities to precisely tailor our training environments, and we have a winning combination.



When fatigue is a matter of life and death

In July 2019, The Times newspaper obtained a leaked draft of a UK government public health green paper. The report links sleep loss with a host of serious physical and mental health conditions, making a strong case for national health guidelines on the quantity and quality of sleep.

But what about those whose professions are incompatible with a healthy sleep routine, such as soldiers, emergency responders, or shift workers?

We asked our Human Performance and Protection team whether science and technology could have the answers…

While humanity has been busy amassing knowledge on everything from subatomic particles to the origins of the universe, how and why we sleep has remained something of an enigma. Only now are we beginning to understand some of the biological mechanisms behind sleep and its effect on health, wellbeing and performance.

For example, scientists working with mice recently discovered a 'housekeeping' system that operates during sleep. The studies suggest that when we are awake, firing neurons produce waste products that accumulate in the brain. During sleep, the contraction of cells within the brain opens up pathways that allow this waste fluid to be washed away, allowing the brain to properly recover.

The more we learn about sleep, the more we appreciate its importance, and so it's encouraging that the government is taking action to address the issue. However, while these guidelines are likely to include recommendations such as a restful environment, sleeping for at least seven hours a night and maintaining a regular routine, certain types of work prohibit these features entirely.

Not everybody gets the luxury of seven hours

A soldier, for instance, often has to sleep in uncomfortable, noisy conditions and at irregular intervals. This impacts their cognitive and physical performance, both in the short term (as an immediate consequence of each poor night's sleep), and in the long term - as the cumulative effects of sleep deprivation take their toll.

Asking our servicemen and women to perform critical, complex and often dangerous tasks following periods of insufficient sleep has always been a major concern - and agencies all over the world are busy researching solutions to it.

Through this research it may be possible to induce deep sleep faster, accelerate the process of waking, and mitigate the risks generated by fatigue. Here's a few of the more promising technologies:

Sleep at the flick of a switch?

By applying magnetic fields to an individual's head, transcranial magnetic stimulation (TMS) can influence electrical activity in targeted regions of the brain.

One of the effects is to trigger 'slow-waves' - these are associated with deep sleep, thought to be important in the recovery of alertness. The ability to induce 'sleep-on-demand' and sustain slow-wave activity for longer could maximise the value of short rest periods.

Although the technology has undergone human trials, more research and development is needed before it can be turned into a deployable product. So far it's only been possible to demonstrate an increase in slow-waves once an individual is already asleep.

And there are more practical barriers to overcome. Study participants have described the equipment used to deliver the magnetic field as noisy and uncomfortable, making sleep more difficult. It must also be positioned precisely on the head, meaning that any movement during sleep can render it ineffective.

Consequently, trials have not yet lasted long enough to demonstrate any benefits – but if the equipment can be properly improved, the technique may yet prove valuable.

Wake up and chew the coffee

For those scenarios in which a good night's sleep just isn't possible, it makes sense to have method or two up our sleeves for countering the negative effects of being poorly rested.

Many of us do this when we start the day with a strong coffee. After about half an hour, the caffeine takes effect and we can get on with being productive – but not everyone can wait half an hour to be at the top of their game.

A soldier or emergency responder may have to make life-or-death decisions within minutes of waking up, so scientists are looking at new ways of fast-tracking the delivery of stimulants. One of the more promising innovations is caffeine gum, which can be absorbed into the bloodstream via the mouth's mucous membranes - taking effect in as little as 12 minutes.

However, more research is needed to understand differences in human responses due to genetic factors and caffeine tolerance built up through regular exposure.

Electrifying performance

In 2014, US military scientists demonstrated that using electricity to stimulate the brain can be twice as effective as caffeine for improving the vigilance of sleep-deprived military personnel - and with effects that last three times longer.

Widely known as "transcranial direct-current stimulation" (tDCS), it's actually possible to buy off-the-shelf tDCS products today.

Still, when tested on servicemen and women tasked with analysing target photos, tDCS reduced fatigue and drowsiness, boosted energy and improved mood when compared to control groups given caffeine and placebos.

And yes, wiring up personnel in this way could transform a team's cognitive performance during complex, critical missions – but what happens to the individuals after the power is turned off?

Will they need time to recover from mental and physical exhaustion? Will the process affect subsequent sleep? Are there cumulative effects from repeated stimulation? We need a better understanding of this technology's short and long term impacts if it's to be implemented safely and effectively.

And this raises another point. Considering that tDCS-capable products are publicly available, is it possible that some personnel might already be using these devices in private - without the knowledge of their employers?

Managing the risks of fatigue

Tired employees create risk, especially in safety-critical roles that demand high levels of concentration and quick, decisive thinking. This risk is best managed by maintaining awareness of the conditions likely to result in fatigue - and identifying the onset of tiredness at the earliest stages.

Whether the response is to administer a stimulant or grant the individual respite from their duties, monitoring their alertness will be crucial in taking the right course of action. There are several existing technologies that can help with this.

Commercially available 'wearables' can monitor sleep using indicators such as heart rate and body movement, and could be made more accurate with the introduction of tools to monitor brain activity and eye movement. Using this data, employers could implement a system where insufficiently rested team members are placed on low-risk duties, while those who've slept properly are given the safety-critical tasks.

Existing technology can also monitor for signs of fatigue and lapses in concentration while tasks are being carried out. For example, some modern cars feature drowsiness detection systems that monitor factors such as steering patterns, driver behaviours, or the vehicle's position on the road.

As another example, eye tracking technology fitted to a computer screen can look for signs of inattention in employees performing observational or analytical roles - such as airport baggage checkers, air traffic controllers, or drone pilots.

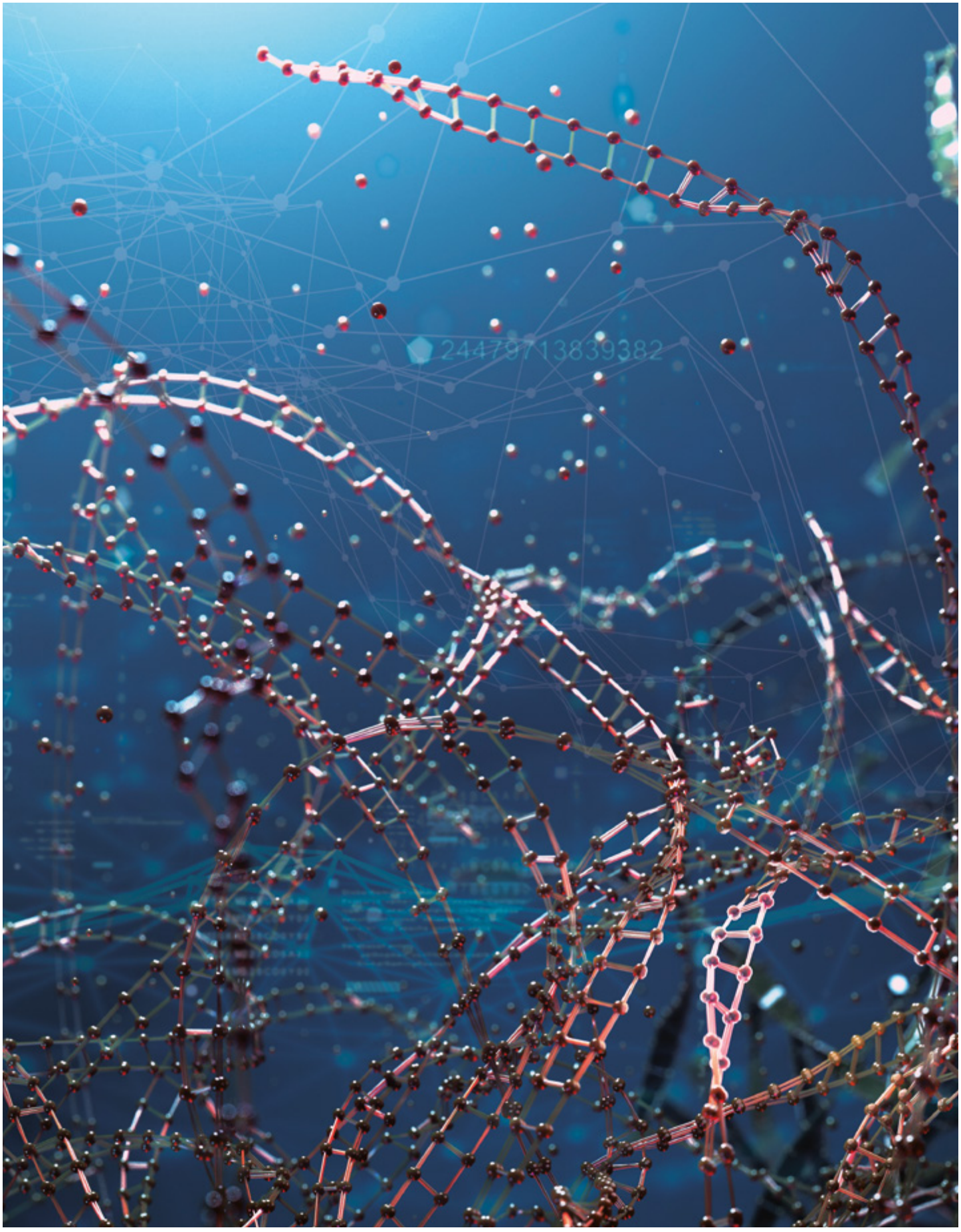
Conclusion

As our understanding of the science of sleep improves, new technologies will capitalise on that knowledge to help us sleep better, wake faster and stay more alert.

In the meantime, whilst we await technological solutions to address the root causes of fatigue, we can employ existing techniques and technologies to observe its symptoms in those performing critical roles. This can help us to make smarter decisions about working rotas, the allocation of duties, and the need for rest periods.

And in high stakes professions, these technologies could literally make the difference between life and death.

HUMAN PROTECTION AND PERFORMANCE **DEEP DIVE**



Natural protection

Theoretical physicist Richard Feynman famously said "What I cannot create I do not understand". The good news is that we can create more today than we have ever been able to before.

This isn't just about new technologies, it's also about new approaches. One of the most exciting is the rapidly advancing field of synthetic biology, which employs engineering principles to design new entities using biological materials and techniques. This fusion of engineering and biology allows us to explore undiscovered characteristics of different materials and tailor them to create technologies with highly specific traits for particular effects.

Synthetic biology is having a significant impact on a range of sectors including pharmaceuticals where it is being used to speed up the development of vaccines, and chemicals, where agricultural waste has been manipulated to become a feedstock for surfactants which blend naturally separating substances such as oil and water. But it is in defence, and particularly in the field of human protection, where some of the most recent and exciting potential is emerging.

Lighter, stronger, clearer armour

We are beginning to see how synthetic biology could be used to design new armour systems. One approach is to engineer biological substances that have very specific adhesive properties. They can therefore be designed to attract two materials together that would otherwise be complex to connect. One example is the use of adhesive peptides (organic substances where the molecules are short chains of amino acids) to attach reinforced nanomaterials to fabric fibres, creating wearable lightweight armour. Initial exploration shows this to be possible and the Dstl is already funding projects in this area.

This ability to create adhesive peptides is beginning to get past the drawbacks of traditional synthetic adhesives, whose limitations affect their efficiency in imperfect conditions such as wet or dusty environments. Zentraxa, a spin out from the University of Bristol is one of the latest companies developing synthetic biopolymers that can stick different materials to each other in extreme environments. The technology has applications for the defence, automotive and medical industries.

Another example of where synthetic biology may enable the design of materials with properties unachievable using conventional means is transparent armour. Windscreens for armoured vehicles, aircraft canopies, goggles for personnel, all require transparency in (for example) visible and/or infrared wavelengths but also need protection from ballistic impact. Various approaches are being investigated including the use of new synthetic biological adhesive systems for producing laminated or layered transparent structures. These could overcome the issues with conventional glues which degrade due to water ingress, potentially causing delamination or loss of transparency. An alternative approach is to use materials such as bacterial nanocellulose fibres as a reinforcing agent in transparent polymers by distributing the fibres within the polymer itself. This could improve impact resistance and reduce weight and thickness over current materials without significantly compromising their transparency.

Initial exploration shows promising results and the Dstl is already funding projects in this area.

Camouflage and anti-glint coatings

In the same way biological entities can be designed to adhere to specific materials, they can also be designed to display other characteristics such as optical properties. These can be finely tuned to react in specific ways to different wavelengths of light. Research is already under way on a new range of bio-engineered 'anti-glint' camouflage. Coated with materials designed using synthetic biology to reduce the amount of 'sparkle' in direct sunlight, this work could make it considerably harder for adversaries to spot soldiers in bright environments.

Similar approaches to material development are being used to explore the creation of contact lenses that can protect people from laser dazzle by absorbing specific wavelengths of light as they enter the eye.

Chemical biological nuclear protection

Synthetic biology can also create new ways of addressing old problems such as identifying hazardous materials in dangerous environments at sites where there has been a chemical attack, a nuclear disaster, or biological contamination. Whilst materials already exist that can help identify an array of different substances, synthetic biology can help us expand the variety of pathogens, microbes, and viruses that can be detected quickly and accurately. New materials can also be designed to detect different hazards at a single site – something that currently requires multiple sensors, each targeting a specific substance.

There remain significant challenges. The amount of data processing required to develop new materials is one of the most pressing. Companies such as LabGenius are melding machine learning to synthetic biology to address the problem but the issue will continue to grow as the amount of data does too. A further issue at the current time is the scalability of materials, which is considered to be a significant barrier for commodity products.

Progress in synthetic biology has been rapid over the past decade and continues to accelerate. The more it develops, the more applications come to light. Its role in keeping people safe is obvious in multiple sectors. Defence is one which can benefit significantly as the sector as a whole starts to adopt more prototype tools for boosting deterrent and improving fighting power. As the culture in defence changes the opportunity to introduce more synthetic biology-derived tools will widen. By then we need to have a much clearer view of how to augment existing approaches for a new bio-engineered era of warfare.

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