Sellafield Ltd

Horizon Scanning

Sellafield Technology Radar: Robotics

Scanning the global horizon for breakthrough science and cutting edge technology from the nuclear sector and beyond.

Promote awareness • Inspire future R&D • Invite discussion

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Foreword

Robotics is having a significant impact across the operations and activities on our site. Across air, land and water applications, Robotics is allowing us to achieve key site milestones more safely, more cost effectively, and more quickly.

To highlight a few:

- We have recently deployed a robotic arm into legacy glove boxes to perform operations without having to place our people at risk. Plus, our skip size reduction facility has automatically dismantled skips to reduce waste volumes and alleviate the demand on storage capacity [Remediation].
- Unmanned aerial vehicle (UAV) inspections allowed us to safely demolish the 52m stack of the First-Generation Reprocessing Plant in a high-risk environment [Engineering & Maintenance with Spent Fuel Management]
- Underwater Remote Operated Vehicles (ROVs) have allowed us to map, clean and manipulate the contents of various ponds to accelerate the schedule for emptying them [Retrievals]

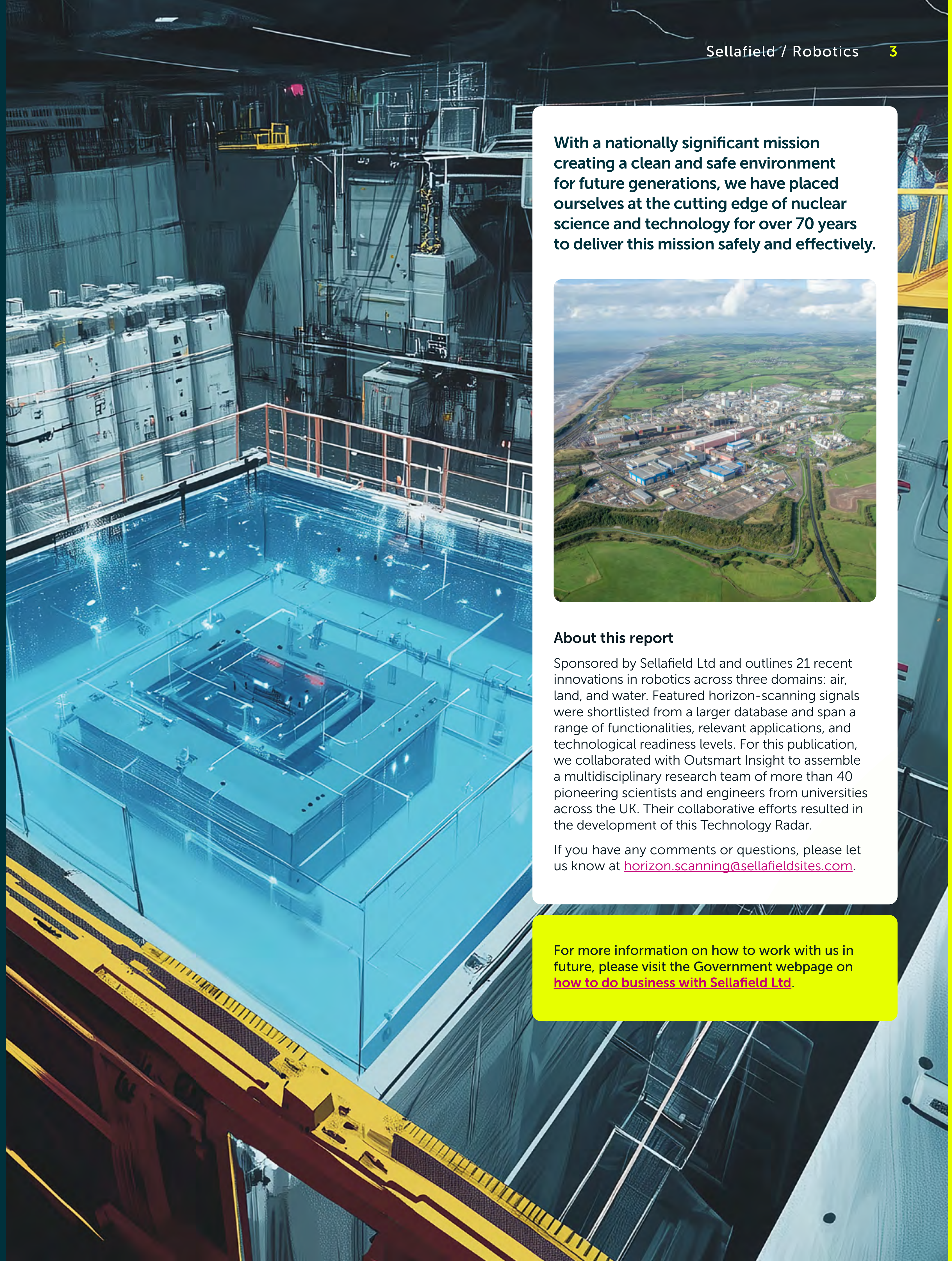
We are now leading the world on Robotics in nuclear, and are rightly proud when told this by our stakeholders; however, we don't make the Robots, we leverage the technology and tools to enhance our performance. That means we need good awareness of how the field is developing and where the market is going, so that we can find new solutions to our problems. We also need to share these emerging capabilities throughout the business, as when new problems emerge, we need awareness of the potential solutions; anyone can connect the dots with the right information.

In this inaugural edition of Tech Radar, we explore a range of signals across air, land and water-based Robotics that could represent the next steps of Sellafield Ltd's Robotics journey. These range from bio-inspired Robots that can navigate confined spaces and even perch on infrastructure to software based on large language models that enable Robots to receive verbal instruction. Together, these signals paint a compelling picture of how the site could be operating in future.

I hope you enjoy reading the first edition of Tech Radar, and gain insights into the future of this diverse technology domain in the context of our nationally significant organisation. As important as Robotics is, it is only one of many components needed to deliver the remainder of Sellafield Ltd's mission, and so I look forward to publishing further editions of Technology Radar to explore these other components.

If you're interested in learning more about technology futures and foresight, the Government has published a toolkit which you can access here.

Robin Ibbotson
Chief Technology Officer, Sellafield Ltd



With a nationally significant mission creating a clean and safe environment for future generations, we have placed ourselves at the cutting edge of nuclear science and technology for over 70 years to deliver this mission safely and effectively.

About this report

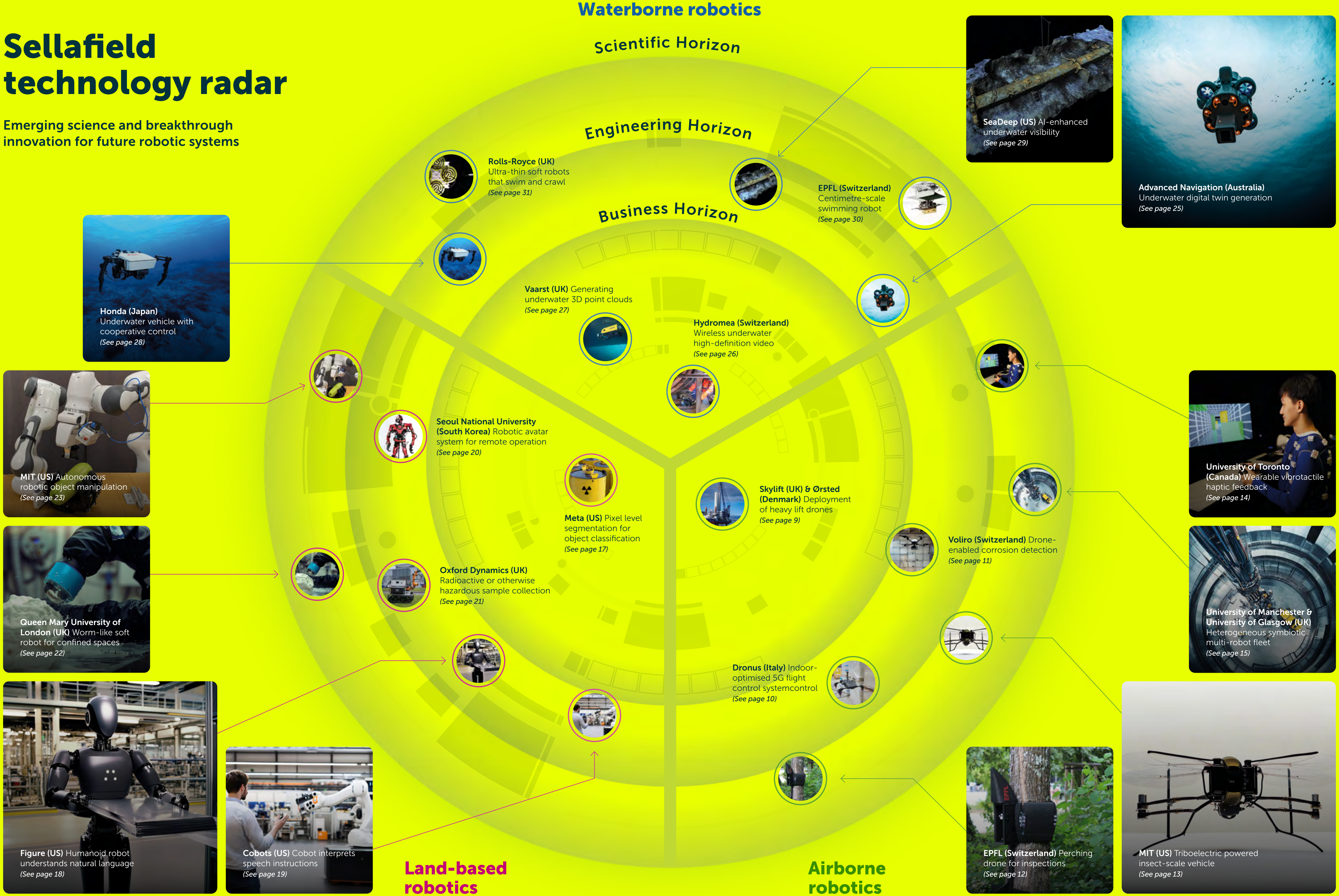
Sponsored by Sellafield Ltd and outlines 21 recent innovations in robotics across three domains: air, land, and water. Featured horizon-scanning signals were shortlisted from a larger database and span a range of functionalities, relevant applications, and technological readiness levels. For this publication, we collaborated with Outsmart Insight to assemble a multidisciplinary research team of more than 40 pioneering scientists and engineers from universities across the UK. Their collaborative efforts resulted in the development of this Technology Radar.

If you have any comments or questions, please let us know at horizon.scanning@sellafieldsites.com.

For more information on how to work with us in future, please visit the Government webpage on how to do business with Sellafield Ltd.

Sellafield technology radar

Emerging science and breakthrough innovation for future robotic systems



Future use cases

Robotic systems are vital for the safe and efficient management of nuclear waste. They facilitate inspections, material handling, and maintenance in hazardous environments, reducing human exposure to danger.

Building on the innovation trends highlighted in this publication, this future vision showcases where advanced robotics could work together across air, land, and underwater environments at Sellafield.

One exciting trend is the emergence and rise of bio-inspired designs. Imagine drones that can perch on infrastructure, conducting detailed inspections with ease. Advances in artificial intelligence will further enhance robotic systems navigation and image processing, while integrated large language models will empower collaborative robots (cobots) to follow verbal commands from an operator with greater accuracy. This synergy of technology will create a safer, more efficient future for nuclear waste management, where human ingenuity and robotic precision work hand in hand.

Heterogeneous swarms

Collaborative swarms of autonomous drones with varied capabilities perform complex tasks such as radiation monitoring or debris removal without human intervention, reducing risks to human workers.

Drone integrated inspection

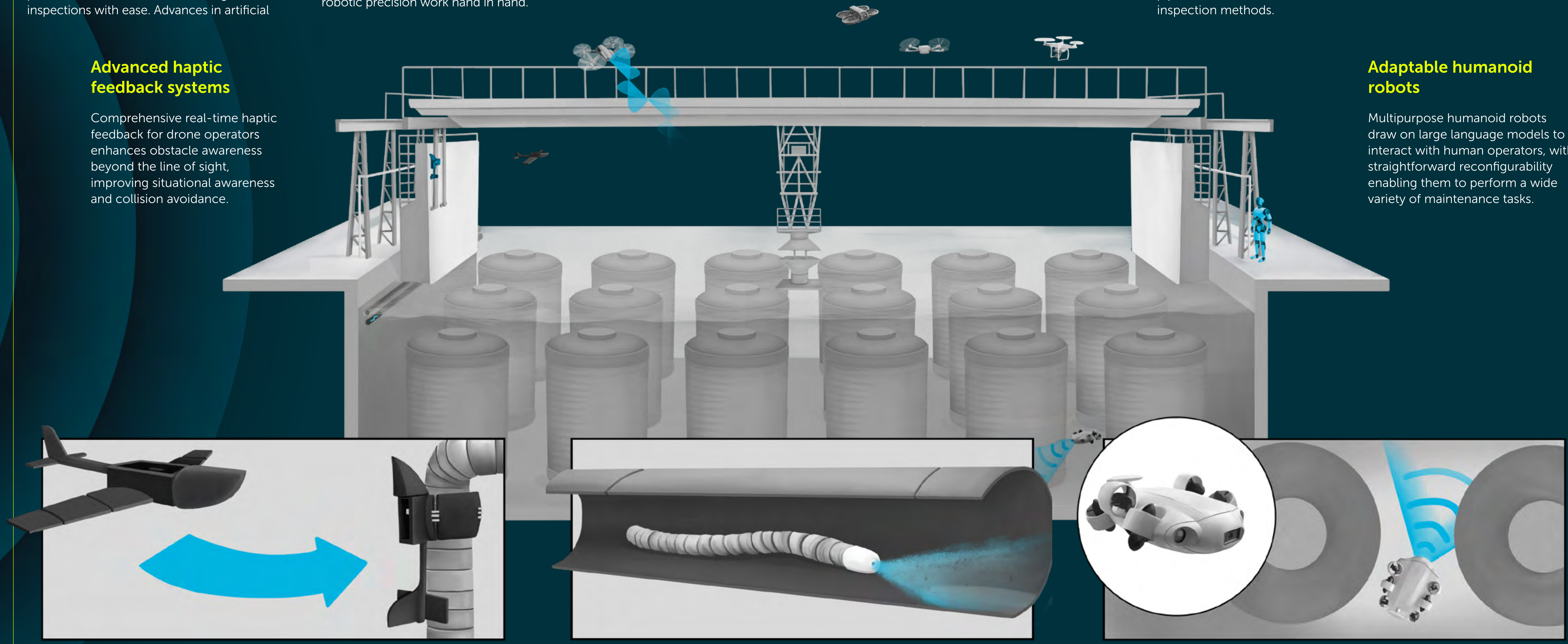
Drone-based pulsed eddy current inspections enable safer, more efficient non-destructive corrosion testing of structures and pipelines than established manual inspection methods.

Advanced haptic feedback systems

Comprehensive real-time haptic feedback for drone operators enhances obstacle awareness beyond the line of sight, improving situational awareness and collision avoidance.

Adaptable humanoid robots

Multipurpose humanoid robots draw on large language models to interact with human operators, with straightforward reconfigurability enabling them to perform a wide variety of maintenance tasks.



Perching robots

Airborne robots capable of bat-like perching attach themselves to vertical surfaces in inaccessible environments, enabling detailed inspection and more complex repairs than hovering aerial vehicles.

Hybrid soft robots

Hybrid robots, combining soft bodies and motor-controlled parts, navigate within confined environments by flexing and deforming to enable inspection and light maintenance.

Underwater 3D modelling systems

Underwater data collection systems that generate real-time 3D point cloud models with sub-millimeter precision accurately characterise infrastructure and enable subsequent inertial navigation.

Airborne robotics

Advancements in drone technology will enable heavier load transport, real-time inspections, improved operator awareness, and efficient nuclear waste management.

Business Horizon

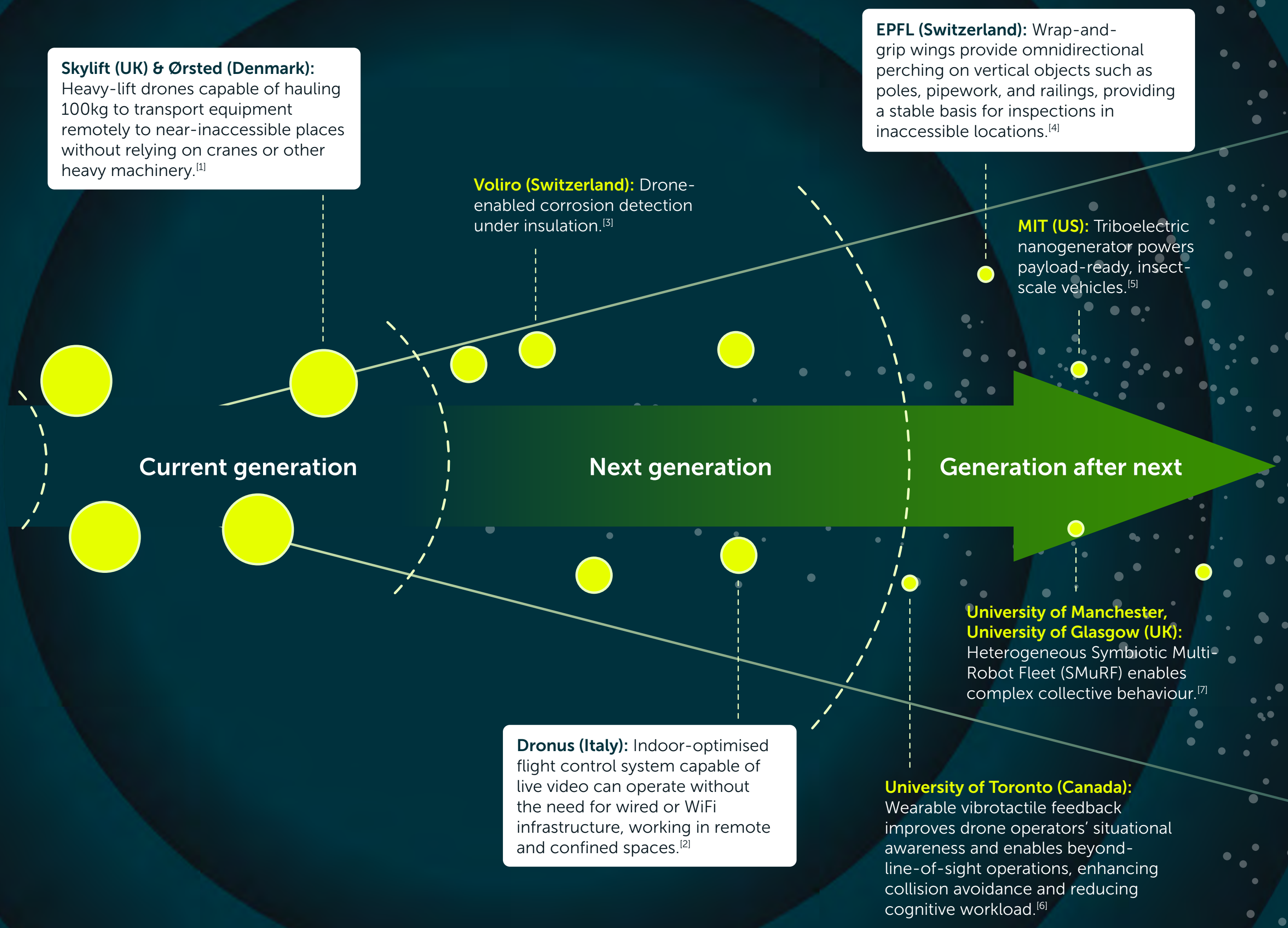
Current-generation technology, in the market and available to buy.

Engineering Horizon

Next-generation technology, in field testing with a clear path to market.

Scientific Horizon

Generation-after-next technology, in laboratories and early stage prototyping.



What to look out for?

0–5 years

Industrial utility drones are gaining widespread adoption, leveraging commercial off-the-shelf (COTS) attachments to integrate advanced sensing and non-destructive testing once limited to handheld tools. While autonomous swarming drones, influenced by defence technologies, are now possible, they remain restricted to small, homogeneous groups focused on surveillance, with limited application in repairs.

5–10 years

Comprehensive site inspections are routinely performed using UAVs, with data feeding directly into digital twins for predictive maintenance. Autonomous drones are deployed at scale in spaces where wireless signals cannot reach or where radio-interference is strong. Bio-inspired drone architectures, like temporary perching capabilities, emerge to improve accessibility.

10–20 years

Autonomous drone swarms now comprise a diverse set of task-specific UAVs. Robotic teams of aerial and land-based systems collectively interpret high-level instructions, autonomously executing multi-step tasks with minimal human intervention. Fleets of micro drones, inspired by insects and just a few cm in diameter, provide rapid detailed inspection in confined spaces.

Credit: Ørsted

Heavy-lift drone combines wings and rotors for long-range transportation

What's the innovation

Space is often restricted on nuclear sites, meaning that some areas are difficult to access. In the future, heavy-lift drones could transport heavy materials or equipment around the facility. However, the conventional quadcopter design is energy intensive, leading to a compromise between flying time/range and payload mass. Skylift's heavy-lift drones combine wings and rotors, allowing it to carry 100kg for over 70km, and have recently been used to transport replacement evacuation and safety equipment to 95 offshore wind turbines for Danish energy company Ørsted.

How it works

- The drone combines a 2.6m wingspan with four rotors, combining the ability to hover with energy efficient forward movement. That allows it to offer both long flight time and high payload capacity, compared to quadcopter drones.
- Despite only weighing 70kg, the drone can transport up to 100kg of cargo, using an attachment located on its underside.
- The drone completed its tasks 10-15x faster than traditional non-drone methods such as helicopters or barge-mounted cranes.

Context

- BAE Systems' T-650 quadcopter drone can carry a 300kg payload, but has a range of just 30km — less than half that of the Skylift drone.
- Heavy lift quadcopter drones developed by Malloy Aeronautics (UK) offer higher payload capacities (up to 180kg), but are limited to short-range missions.
- Avy's (Netherlands) Aera drone focuses on medical deliveries, combining a 5kg payload with an extensive 90 minute flight time.

What's next

Skylift is working on enhancing the drone's ability to carry heavier loads and its operational range, expanding its applicability to different scenarios.

View source
For sale
Source:
Corporate R&D
Origin:
Europe

Further reading
Watch the Skylift drones in action

[View source](#)
Real world testing
Source:
Corporate R&D
Origin:
North America

Credit: Dronus

Smart factory drones use mmWave 5G for high capacity data sharing

What's the innovation

Indoor autonomous drones can be used for inventory checking and radiation monitoring. However, barriers like thick walls, ceilings and other protective infrastructure restrict GPS and WiFi signals, limiting a drone's ability to navigate and send back live data. To address this, Dronus (Italy), in collaboration with Ericsson (Sweden) and Qualcomm (US) successfully demonstrated an autonomous drone with live video streaming, using mmWave 5G (24GHz to 100GHz, with a higher bandwidth than conventional 5G networks) over a private mmWave 5G network, at an Ericsson Smart Factory.

How it works

- When flying, drones typically use point to point WiFi links, which could lose signal if they find themselves in dead spots between routers or need to travel beyond WiFi range.
- mmWave 5G utilises higher frequency waves than WiFi or standard 5G meaning it can carry large amounts of data and provide reliable high bandwidth communications over the entire factory.
- Originally intended for inventory management, the drone's indoor-optimised flight control system combines cameras with recognition algorithms to orient itself within its surroundings.

Context

- 5G enabled drones utilise internal modems, capable of up to 3 Gbps upload and 7.5 Gbps download speeds along with much lower latency than conventional WiFi.
- An alternative industrial application of mmWave 5G is Inxpect's (Italy) development of high resolution radars that assist robot navigation.
- Other alternatives to WiFi-enabled drone control include position, navigation and timing systems based on computer stereo vision, which is being deployed by companies such as Bluespace AI (US).

What's next

With this demonstration serving as a proof-of-concept, Ericsson initially aims to use 5G drones for autonomous barcode scanning to assist with inventory management.

Further reading
Read more about the benefits of 5Gs drones

Drone with electromagnetic pulses detects hidden corrosion

What's the innovation

Hidden corrosion can occur in buried pipelines, concrete-encased structures, and storage tanks, potentially leading to structural failure and contamination if unnoticed. Checking for corrosion can require physical removal of protective or insulating material, which increases costs and may damage the underlying structure. A solution could come from Voliro (Switzerland), which claims to have developed the first drone with an integrated pulsed eddy current module — a non-destructive testing (NDT) method particularly well suited to identifying corrosion.

How it works

- The module, designed by Sixpec (Netherlands), emits electromagnetic pulses that create a changing magnetic field. This field passes through coatings and induces eddy currents into any ferrous material behind them.
- By measuring the electromagnetic response, the drone can detect variations in the eddy current flow that indicate cracks and corrosion induced degradation, especially if close to the surface.
- The module is integrated into the Voliro T drone which has an adaptable payload capable of integrating various inspection tools.

Context

- An alternative to pulsed eddy currents is ultrasonic testing, which is regarded as better suited to identifying deeper lying corrosion and cracks in thick welds and bulk materials.
- Ultrasonic corrosion testing has been integrated into drones by Skygauge Robotics (US) and into wall-climbing robots by Gecko Robotics (US).
- Another drone explicitly targeted at NDT applications is Flyability's (Switzerland) Elios 3, a cage drone that uses a 4K camera and LiDAR sensor and is targeted at confined environments such as underground mines and cement silos.

What's next

Voliro has begun an early-adoption program with limited customers, with general availability to be announced later in 2024.

Further reading
Read more about how drones improve infrastructure inspection

View source
Real world testing
Source:
Startup
Origin:
Europe

Bat-like drone wraps its wings to cling to vertical structures

What's the innovation

Nuclear sites contain many high areas that are difficult or dangerous for humans to inspect, such as reactor buildings, ventilation stacks, or waste storage silos. Drones are commonly used for such inspections, but a team at the Federal Institute of Technology Lausanne (EPFL, Switzerland) has developed an interesting evolution – a gliding drone that can land on curved vertical surfaces, such as poles or pipes, using a bat-like 'wrap-and-grip' perching manoeuvre. This would enable measurements at height, without the power consumption or instability of hovering drones.

How it works

- The plane-shaped drone has an upturned nose so that, upon impact with the pole, the body naturally falls from horizontal flight to a vertical position up against the pole.
- Upon impact, the drone releases its foldable segmented wings through a latch system, wrapping them around the vertical pole.
- The centre of mass is maintained throughout the procedure to minimise the pitch-back effect, which could cause the drone to roll backwards off the target.

Context

- An alternative vertical surface attachment mechanism is being developed at Imperial College (UK), combining a quadrotor drone with a winch-tethered magnet that allows it to land on and slide along vertical surfaces for repair or inspection.
- The same team is developing another drone that uses a spine-like hooking device to dock itself to a variety of irregular surfaces from where it can orient itself into any position relative to the surface.
- Vishwa Robotics (US) has developed a bird-inspired perching mechanism for a micro aerial vehicle that utilises mechanical 'claws' rather than bat-like wings.

What's next

The EPFL researchers plan to develop autonomous targeting capabilities by integrating sensor-based pole detection and thrust-assisted climbing.

Further reading

Watch the perching robot in action

Credit: Ørsted

View source

Laboratory testing

Source:
University lab

Origin:
Europe

Triboelectric generator powers the wings of robot insects

What's the innovation

Sensing in the small spaces and structurally complex environments of nuclear facilities can be dangerous, even for robots. MIT (US) researchers have developed insect-like soft micro aerial vehicles (MAVs), which are resilient to collisions thanks to their 'soft' components. As with many soft robots, the wings, which weigh less than a gram, are moved by dielectric elastomer actuators. To produce the 1-2kV needed to power these actuators, the researchers have developed a compact triboelectric nanogenerator (TENG) that removes the need for comparatively bulky inductors or transformers.

How it works

- TENGs generate electricity through contact and electrostatic induction when two dissimilar materials rub together.
- Orienting two TENGs on the same geometric plane improved compactness, yielding a 280% increase in peak-to-peak voltage and a 920% increase in energy relative to conventional TENG setups.
- The configuration can deliver over 1500V and 110mW without inductors or transformers, giving the compact MAV a lift-to-weight ratio of 1.75.

Context

- Previously, the same research group applied lasers to precisely repair or modify soft MAVs damaged during operational collisions.
- Collision damage to rigid drones can be mitigated by using self-healing materials, with researchers at the University of Bristol (UK) utilising a light-responsive liquid resin to repair cracks mid-flight.
- TENGs can also be used for energy harvesting, with IMRE (Singapore) applying the technology to create self-powered wearable electronics for real-time health monitoring.

What's next

The research group is developing scalable fabrication methods for MAVs with the aim of demonstrating swarm flights, and also working to further improve power density.

Further reading

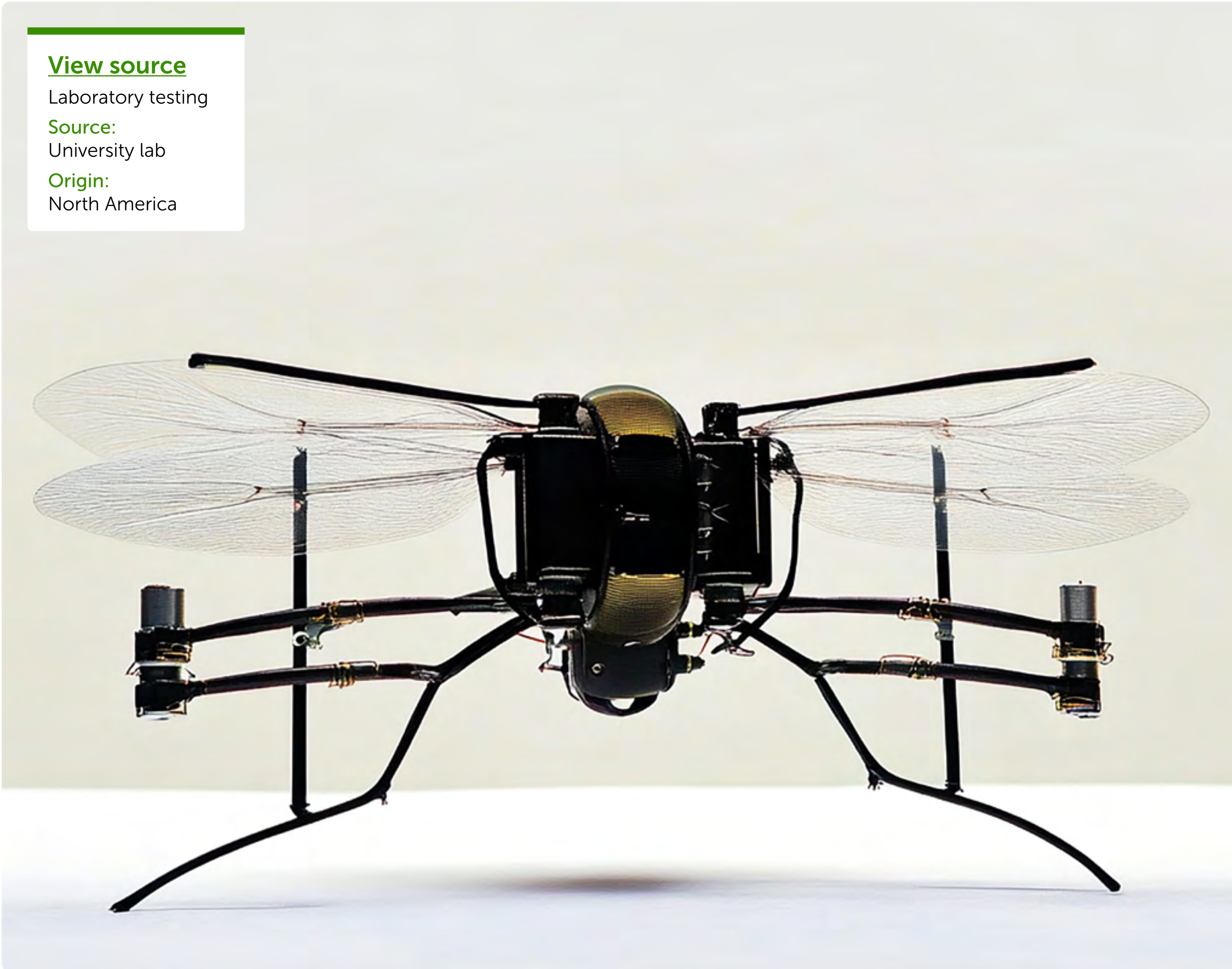
Read more about the Soft and Micro Robotics Laboratory at MIT

View source

Laboratory testing

Source:
University lab

Origin:
North America



View source
Laboratory testing
Source:
University lab
Origin:
North America

Credit: Qilong Cheng

Haptic drone operator vest vibrates when collisions are imminent

What's the innovation

Drone operators sitting at a remote screen with a joystick have limited perception of the world around their drone, due to physical separation and absence of proprioceptive feedback (the sense of one's own body position). That limits their ability to sense obstacles during drone-based inspections or maintenance, and increases the risk of collisions that could damage structures. To improve drone control, researchers from the University of Toronto (Canada) claim to have developed AeroHaptix, a vest that uses vibrations to alert an operator to obstacles, including those out of their field of view.

How it works

- AeroHaptix features 32 vibrotactile units located on the operator's upper body which vibrate according to the position of nearby obstacles.
- The layout of the units, and their supporting algorithms, are optimised to map body and obstacle position for intuitive obstacle perception.
- Wearing the haptic vest was shown to reduce collisions as much as handheld feedback systems while delivering increased situational awareness and reducing the operator's cognitive workload.

Context

- Vibrational cues are not the only method of haptic feedback, with Teslasuit (UK) offering a thinner haptic feedback suit that uses electrical muscle stimulation (EMS) and transcutaneous electrical nerve stimulation (TENS).
- Researchers at Cranfield University (UK) have taken an alternative approach to improving operator situational awareness, providing feedback using virtual springs that progressively raise controller resistance as obstacles get closer.
- A team from LMU Munich (Germany) has flipped the problem, using drones to move around humans working in virtual reality to deliver haptic feedback that mimics their virtual environment.

What's next

The researchers are developing different vibration patterns to provide more nuanced feedback on different obstacle characteristics, and are planning real world testing using commercial drones.

Further reading

Read about how haptics are being implemented in the drone industry

Robots with different form factors collaborate to measure radiation

What's the innovation

Robots are invaluable for measuring radiation levels around nuclear facilities, where human exposure must be kept to a minimum. Since measurements must be acquired both aerially and from the ground, an ideal measurement system might simultaneously deploy a fleet of different robots. However, these robots are rarely designed to work together, making sequential measurements with different robots inefficient and potentially inconsistent. Now, engineers from the Universities of Manchester and Glasgow (UK) have developed software that enables a swarm of air and land robots with different programming languages to collaborate autonomously to measure radiation.

How it works

- A cyber-physical software architecture enables real-time data exchange between a Symbiotic Multirobot Fleet (SMuRF) of six heterogeneous robots, digital systems, and human operators.
- A 3D digital twin provides a virtual environment for human operators to interact with the fleet, supporting query-based learning where robots solicit human input to refine their understanding to deliver improved task completion times.

Context

- The system's effectiveness has been validated in a simulated nuclear facility, mimicking real-world inspection scenarios during a Post Operational Clean Out (POCO).
- For purely aerial observation, Exyn Technologies (US) has developed autonomous drone fleets that collaborate to map GPS-restricted environments.
- Collective robot behaviour using decentralised coordination strategies has been developed by researchers from NASA's Jet Propulsion Laboratory (US) to map unknown environments.

What's next

The engineering team aims to scale autonomy through symbiotic interactions, and plans to transition from simulated environments to real-world nuclear facilities.

Further reading

Read more about the SMuRF collaborative robots

View source
Laboratory testing
Source:
University lab
Origin:
Europe

Land-based robotics

AI advancements will enhance land-based robots' communication and problem-solving, enabling collaboration, mimicry learning, and faster reconfiguration through verbal commands.

Business Horizon

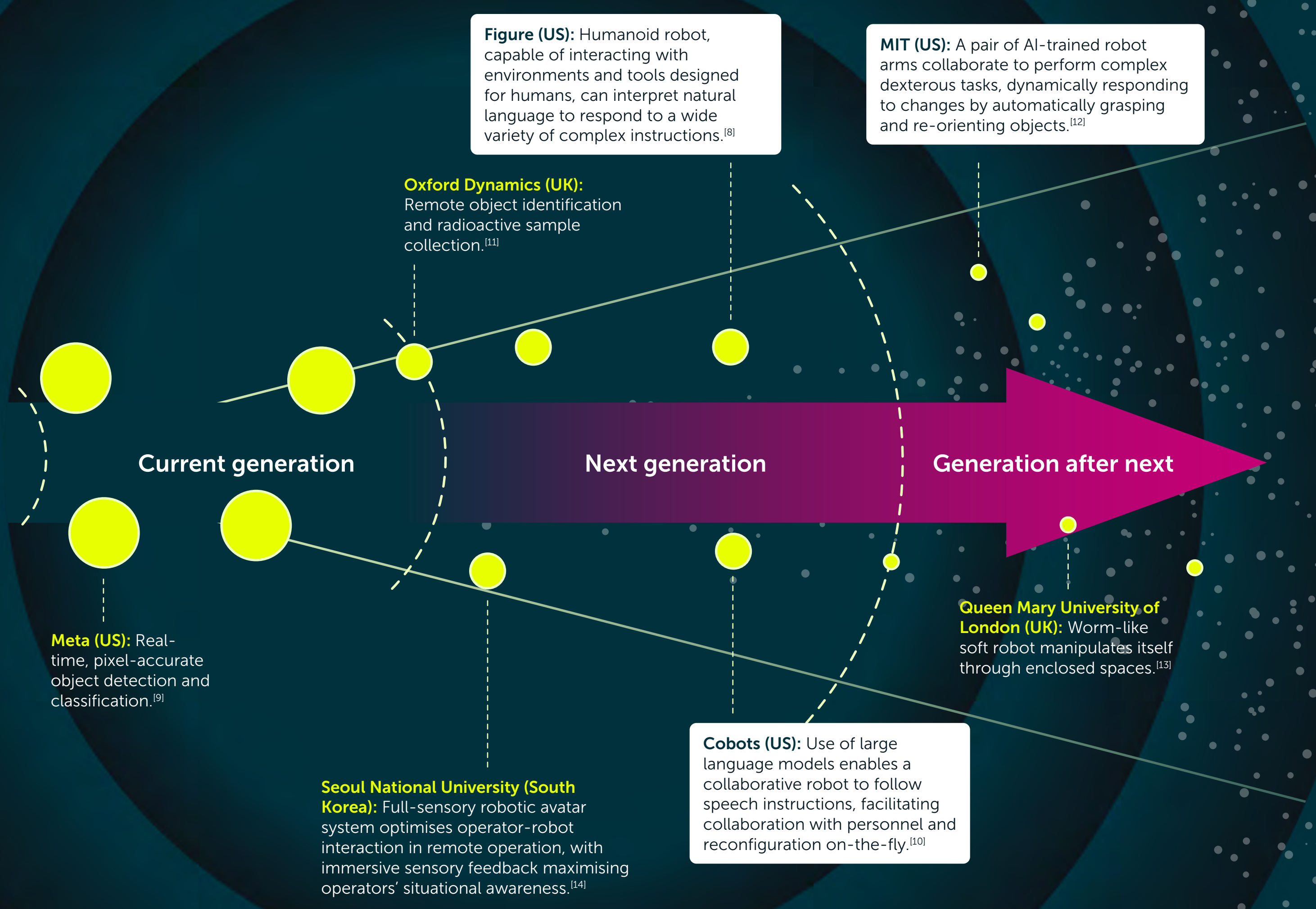
Current-generation technology, in the market and available to buy.

Engineering Horizon

Next-generation technology, in field testing with a clear path to market.

Scientific Horizon

Generation-after-next technology, in laboratories and early stage prototyping.



What to look out for?

0–5 years

Real-time object segmentation has advanced detection and identification, allowing pixel-perfect classification in live video feeds. Combined with sensor fusion and enhanced optical imaging, robots now operate more efficiently in unfamiliar or low-visibility environments. Natural language processing (NLP) is also being introduced, enabling non-specialists to give clear, simple instructions with ease.

5–10 years

NLP is becoming standard, facilitating seamless communication with humanoid robots that rapidly adapt to new tasks. When human oversight is needed, advanced sensory feedback, including haptic suits, provides immersive situational awareness. AI advancements enable coordinated teamwork among multiple robots, including aerial and underwater systems, for tasks like material handling and inspection.

10–20 years

Robots achieve human-like tactile precision, while Artificial General Intelligence (AGI) allows them to reason through abstract tasks, like safely handling radioactive materials, without detailed guidance. Soft, deformable robots with versatile locomotion methods now collaborate to navigate and inspect complex, confined spaces, including pipework and collapsed structures, enhancing operational flexibility.

Pixel level object tracking in video could support automated inspection

What's the innovation

Tracking objects in video footage could improve safety, for example by visually checking that moving manufacturing components are behaving correctly, or tracking radioactive waste containers through the facility. However, existing software struggles to track objects moving fast relative to the frame rate, or when the tracked object changes orientation over time. Meta's (US) new image segmentation algorithm, the Segment Anything Model 2 (SAM2), claims to solve these problems, with a one-click method for selecting objects in images, which it then tracks for the rest of the video.

How it works

- SAM2 processes images within a video to identify if an individual pixel belongs to a given object and to identify object boundaries and backgrounds.
- It uses a memory attention system to define the state of the current frame based on the preceding ones, and masks the pixels that represent the tracked object.
- The training set used pre-labelled images for the model to learn how objects evolve through video, but future tracking based on the memory attention system can be made with a single point and click.

Context

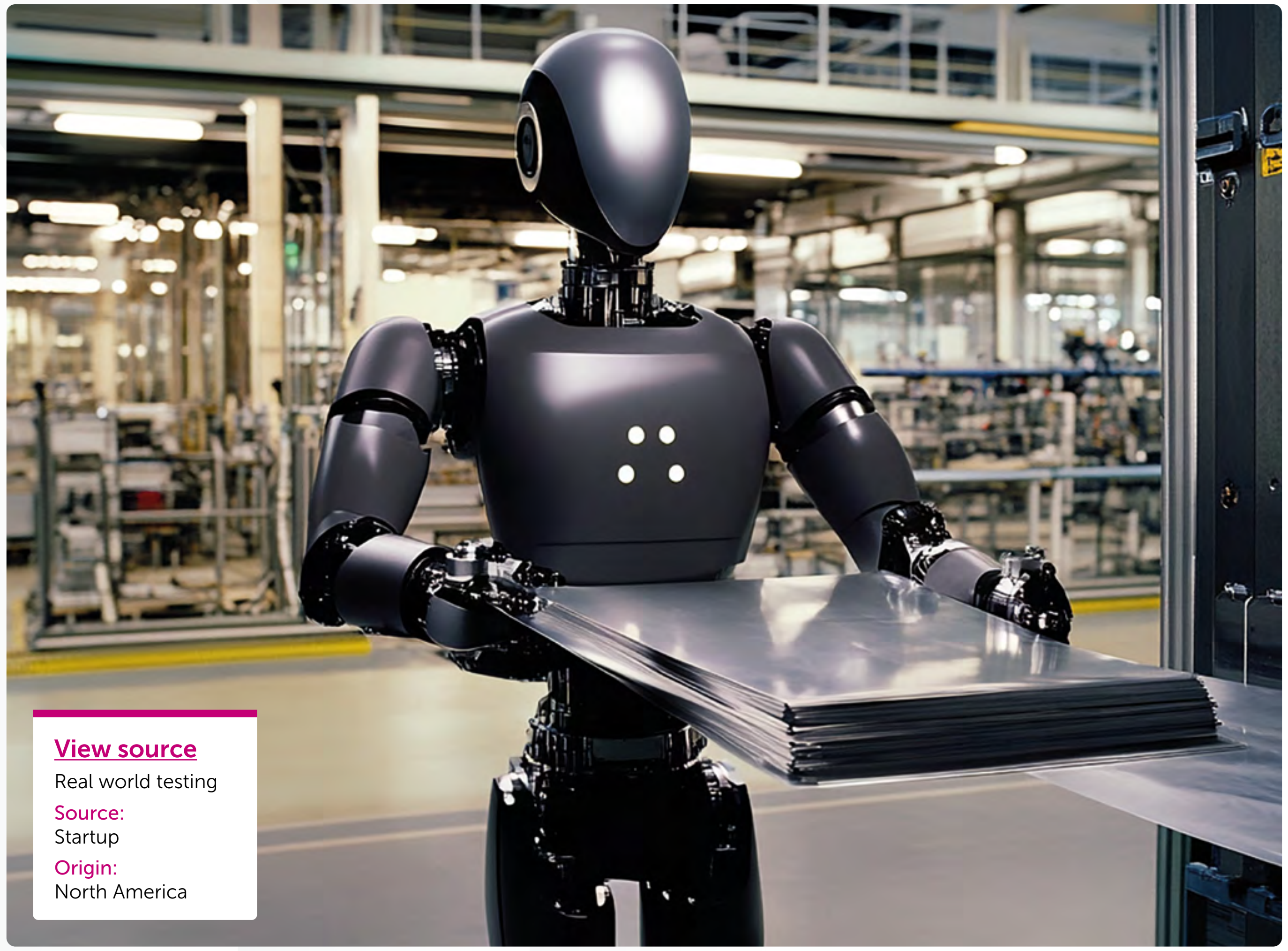
- As a foundational model, SAM2 is trained on a diverse dataset (around 1 billion image frames) and can be fine tuned to improve performance on specific tasks.
- IBM (US) has released Maximo Visual Inspection, an image segmentation product specifically for quality control, inspection, and defect detection.
- Google (US) tested its Visual Inspection AI on robot-welded seams, to identify anomalies at critical structural connections in metalwork.

What's next

The researchers behind SAM2 have published the model and data for anyone to use for free under an Apache licence, along with the training data, and are planning to integrate the algorithm into augmented reality devices.

View source
For sale
Source:
Corporate R&D
Origin:
North America

Further reading
Read the research paper describing SAM2



View source
Real world testing
Source:
Startup
Origin:
North America

Factory deployment of humanoid robot capable of rapidly learning new tasks

What's the innovation

Humanoid robots can interact with tools designed for people, and could complete wide-ranging tasks such as cutting pipes and transporting radioactive materials across awkward terrain. Figure's (US) latest humanoid, the Figure 02 offers human-like movement and dexterity in its arms and fingers, and has already been deployed inserting sheet metal parts into fixtures at BMW's Spartanburg (South Carolina) factory. The robot is 1.68m tall, can carry 20kg, and has a runtime of five hours. It uses an AI-based language system that reportedly allows it to be taught tasks via speech, without needing to be programmed for each specific task.

How it works

- OpenAI's (US) large language model (LLM) and additional AI capabilities are integrated within the robot, allowing it to learn from past interactions and continuously improve communication and performance in unstructured real-world environments.
- The large language model outputs are interpreted by a separate neural network that provides instructions at 200Hz to a whole body controller.
- Figure has demonstrated that the humanoid can converse while performing manual tasks such as sorting waste or cleaning dishes autonomously.

Context

- Figure closed a £500 million Series B round in February, which drew participation from the investment arms of Amazon, Intel, Nvidia, Microsoft, OpenAI, and Samsung.
- Agility Robotics (US) is also investigating generative AI models for its humanoid robots to improve communication skills, but this has yet to be deployed in a commercial environment.
- OpenAI (US) recently invested in 1X (Norway), which is developing AI-powered humanoids for use in homes.

What's next

Following the successful BMW trial, Figure is currently scaling up its manufacturing, and hopes to bring its humanoid robots to market in the next few years.

Further reading
Watch Figure's robot perform speech to speech reasoning

Collaborative robots can take verbal instructions thanks to large language models

What's the innovation

Most robots do one thing well, leading to an expensive assortment of task-specific systems. Many factories would like fewer but multipurpose collaborative robots (cobots), but manufacturers struggle to programme robots for every task they might encounter. By using large language models (LLMs), voice recognition and speech synthesis to allow its robots to follow complex verbal instructions from human operators, startup Cobots (US) aims to enable task allocation on the fly without complicated reprogramming.

How it works

- The cobot uses voice recognition systems that capture human speech, which is then processed by LLMs like GPT-4, analysing linguistic structure and context to discern the user's intent.
- The LLM describes a sequence of actions for the cobot to follow and a custom programming language bridges the gap between speech and robot action.
- The cobot can learn from each interaction, refining its interpretation of commands and adapting its behaviour over time to optimise efficiency.

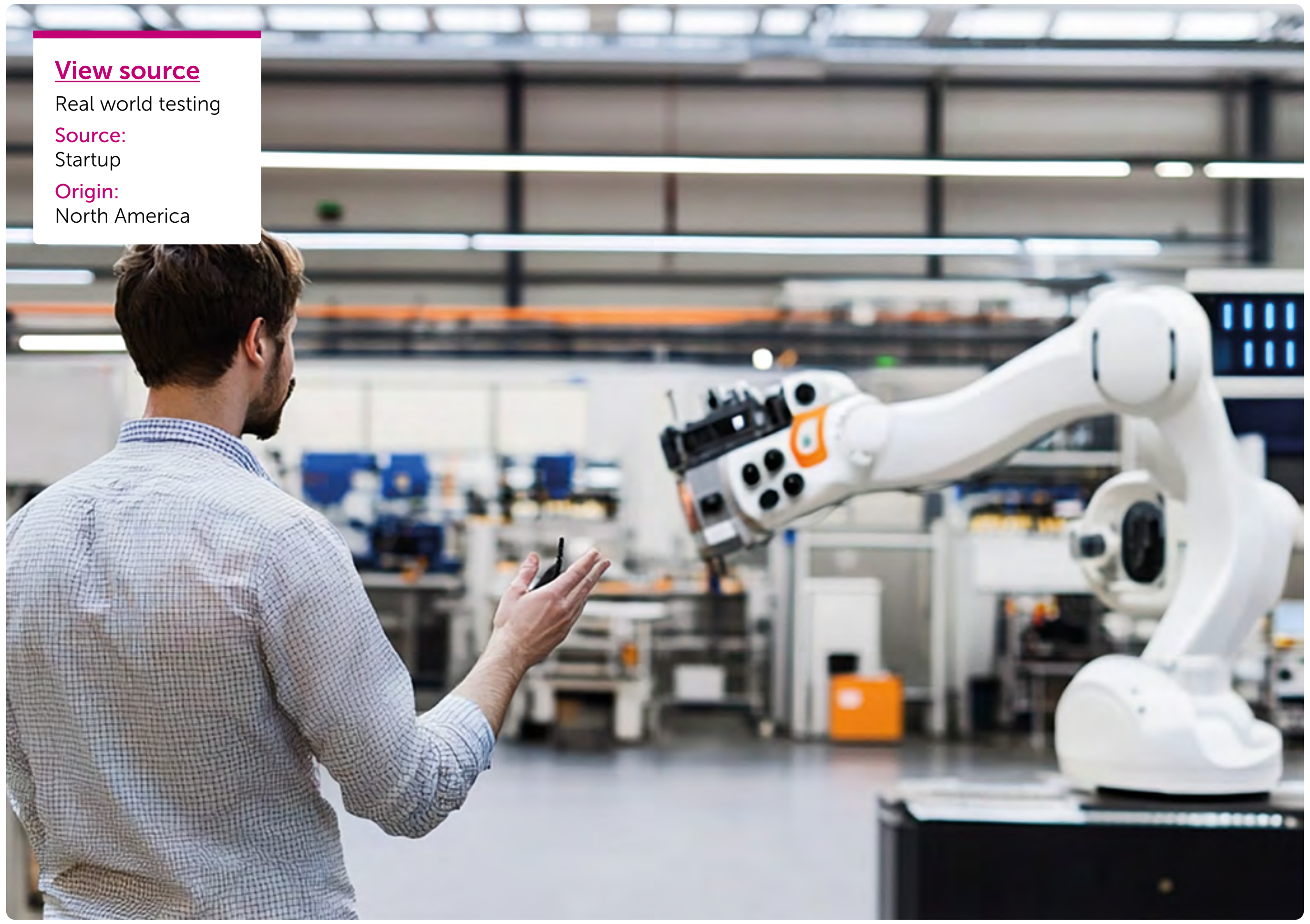
Context

- Due to their ability to work alongside people, cobots enable partial automation of a manufacturing process, but are typically designed for a set of similar tasks such as collecting items from a warehouse or performing inspections.
- Multipurpose, easily reprogrammable cobots will require dexterous manipulation capabilities. Scientists at the University of Georgia (US) have developed networked smart sensors and soft robotic grippers, which are expected to widen cobots' capabilities.
- NVIDIA (US) recently modified open-source LLMs to run on local devices, eliminating the influence of network disruption when interacting with the cobots.

What's next

Cobots plans to move LLM processing from the cloud to onboard, minimising both latency and the impact of network outages to ensure seamless communication with human colleagues and eliminate cloud-based security concerns.

Further reading
Watch a demonstration of collaborative robots



View source
Real world testing
Source:
Startup
Origin:
North America

Combining sensors and haptics helps robot operators identify objects by touch

What's the innovation

Confirming that newly-manufactured nuclear waste containers are defect-free is essential to ensure they meet design standards, but inspections are time-consuming and can be prone to human error. Now, a visual inspection system from startup Averroes (US) could automate this process, even where training data is sparse. It uses deep learning algorithms to analyse images, distinguishing between minor cosmetic flaws, dimensional inconsistencies and incorrect assembly by comparing live images with reference models in real-time, achieving over 99% accuracy. Unlike manual checks, Averroes' deep learning models catch even minute or hidden defects, reducing rework, improving traceability and providing reliable compliance data.

How it works

- Deep learning models learn normal features from reference images, then flag deviations in new images as defects.
- Averroes applies this concept to industrial defect detection, training its models on at least 20 images of good and faulty parts ranging from circuit boards to energy infrastructure.
- The system can reliably spot defects as small as 5μm while reducing false positives by 95% relative to traditional inspection methods.

Context

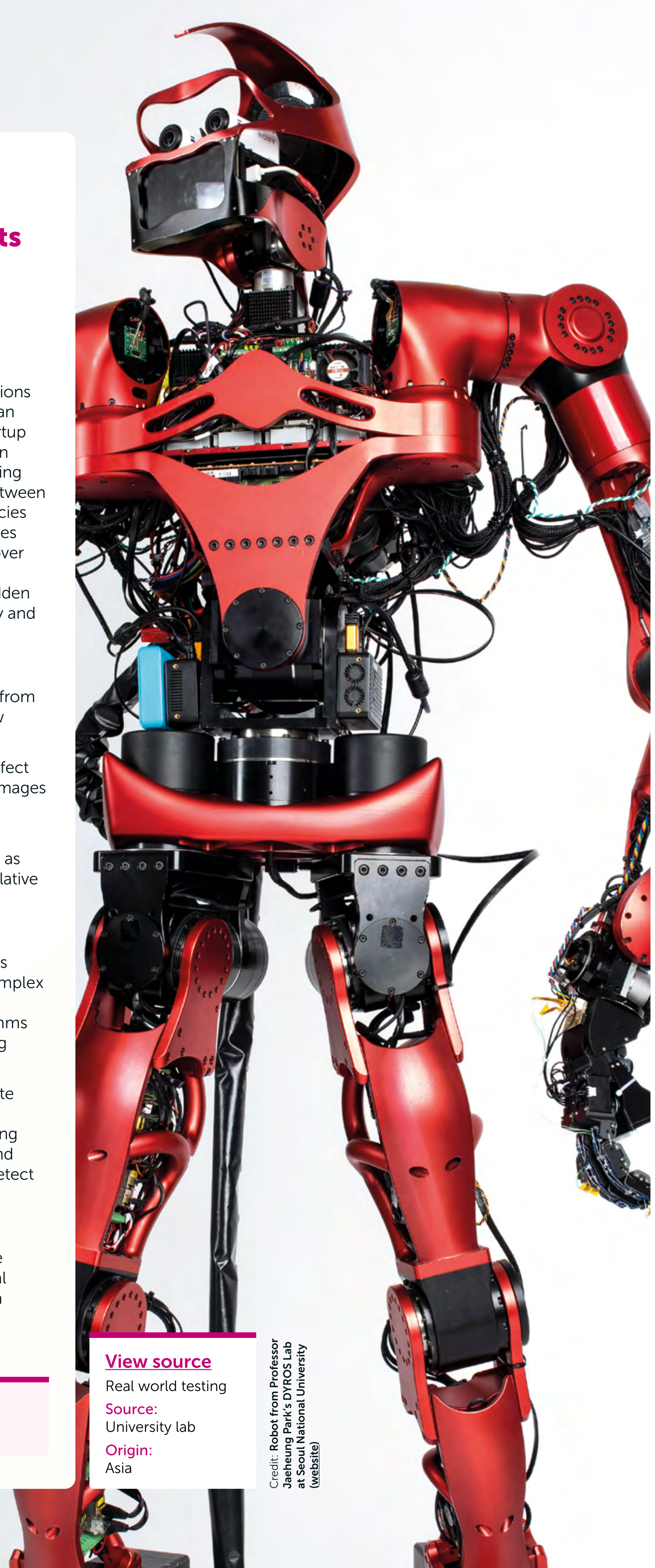
- Earlier automated optical inspection systems were prone to missing subtle defects on complex surfaces, often generating false positives or negatives. In contrast, deep learning algorithms can learn complex patterns, vastly improving defect capture.
- Visual inspection tools could soon incorporate radiation measurements, with researchers at Oak Ridge National Laboratory (US) developing computer-vision-aided Compton imaging and advanced deep learning to simultaneously detect micro-defects and radiation leaks.

What's next

Averroes plans to upgrade its system to enable predictive maintenance, integration with digital twins and real-time accuracy improvement via user feedback.

Further reading

Read about a robotic Avatar competition



View source

Real world testing

Source:
University lab

Origin:
Asia

Credit: Robot from Professor Jaeheung Park's DYROS Lab at Seoul National University (website)

First qualified autonomous ultrasonic inspection of nuclear infrastructure

What's the innovation

While robots are often well suited to handling contaminated material such as radioactive waste, sometimes such materials need to be collected and safely transferred to human-operated labs. Strider, a robotic platform developed by Oxford Dynamics (UK) for the UK Department for Environment, Food & Rural Affairs does just that. The robot can operate on all terrains thanks to its tracked wheels, and can identify and collect radioactive material samples, which it places in protective containers for subsequent analysis and disposal.

How it works

- Strider features a highly mobile robotic arm mounted onto an all-terrain tracked wheel base.
- The robot can be remotely controlled by an operator, but also uses infrared, radar, and LiDAR to map and navigate terrain, and perform certain tasks autonomously.
- It can retrieve contaminated objects and store them in sealed containers within a case behind its armature, returning them safely to a laboratory.

Context

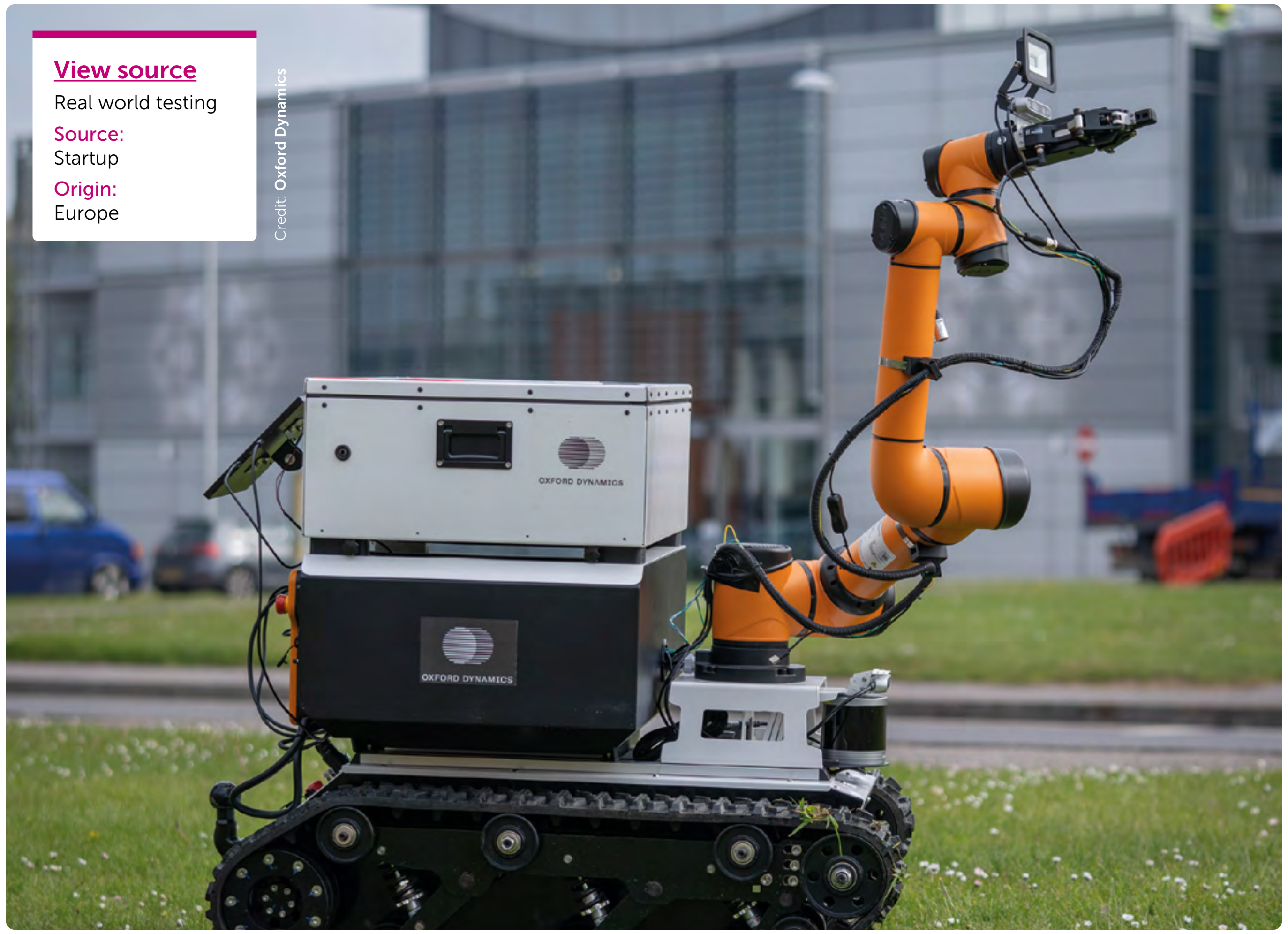
- Other radiation detection robots include a technology implemented into Boston Dynamics' (US) 'Spot' robot dog to identify hot spots within irradiated zones, developed by a UK consortium comprising Sellafield Ltd, Createc, and the UK Atomic Energy Authority (UKAEA).
- Handling radioactive material is not restricted to surface robots. KOKS Robotics (Netherlands) has developed a submersible robot for removing liquid pollution from contaminated tanks within nuclear power plants.
- In September 2024, a robot with a telescopic arm and a small manipulator was used to remove a piece of melted and solidified fuel debris in the Fukushima Unit 2 reactor.

What's next

Oxford Dynamics is working on integrating an AI system that will enable Strider to automatically identify the optimum way to handle materials, by detecting individual objects and estimating their weight and surface quality.

Further reading

Read about the deployment of robots in decommissioning Dounreay power station



View source

Real world testing

Source:
Startup

Origin:
Europe

Credit: Oxford Dynamics

View source
Laboratory testing
Source:
University lab
Origin:
Europe

Soft snake-like robot precisely deposits decontaminating agent in pipes

What's the innovation

While the use of soft snake-like robots for inspecting pipes is relatively established, their soft nature makes it hard to precisely control attachments, such as sprayers of expanding foam used to seal pipes and encapsulate hazardous materials. Scientists at Queen Mary University of London (UK) claim to have a solution: a soft robot, measuring approximately 30cm in length and weighing less than 1kg, which combines the flexibility of a soft body with the precision of a hard motor-controlled head. In tests inside a pipe, it was able to deposit a liquid decontaminating agent with over 95% success.

How it works

- The soft body is made up of a pneumatic 'vine', consisting of overlapping nylon strips sewn together. This is propelled forward by pressurised air, with the tip extending similar to the way a plant grows, in a process known as eversion.
- The robot's head is made from solid material that can carry sprayers supplied via a hose, with integrated cameras, which is manoeuvred via remote controlled motors and actuators.
- The user controls the 'vine' via a joystick, with a separate steering mechanism for the tip.

Context

- Combining a rigid motorised controllable head with a soft robot would also facilitate detailed pipe and machinery inspection by enabling a camera to be precisely focused on a specific area.
- While Queen Mary's soft robot is tethered, GE (US) is developing untethered soft robotics, specifically an electronic skin-innervated platform resembling an inchworm for aircraft inspections.
- CNRS (France) is exploring a different method for manoeuvring through pipes, reporting a bio-inspired robot that mimics the motion of a caterpillar rather than using eversion.

What's next

Future research will focus on integrating AI to automate the robot's motion, based on certain stimuli. If combined with gyroscopic tip tracking, this computer vision could be used to create a 3D map of the spraying area, providing real-time feedback to the operator.

Further reading
Read more about recent developments in soft continuum robotics

Two robotic hands work collaboratively to achieve human-like dexterity

What's the innovation

Human-like dexterity in robots could let them autonomously operate equipment designed for humans, or precisely manipulate radioactive or chemically hazardous materials. A major challenge is designing a robot hand that can continuously reorient an object. This is hard for computer systems to model due to frequent breaking of contact, high-dimensional control space, and robotic perception challenges due to occlusions. To address this, researchers at MIT (US) have developed a robotic system with two arms that collaborate to complete tasks such as peeling vegetables with human-like skill, training via reinforcement learning.

How it works

- The robot comprises a low-cost robotic hand mounted on an arm, which can grasp and reorientate objects. A second arm uses a gripper to hold a tool, like a vegetable peeler.
- The two arms were trained via reinforcement learning to cooperate. The system learnt to stop peeling and to reorientate the vegetable where necessary to complete the task.
- The robot was trained in a simulated environment where it received an algorithmic reward for correct object rotation and reorientation, and was 'punished' for manipulating the object incorrectly.

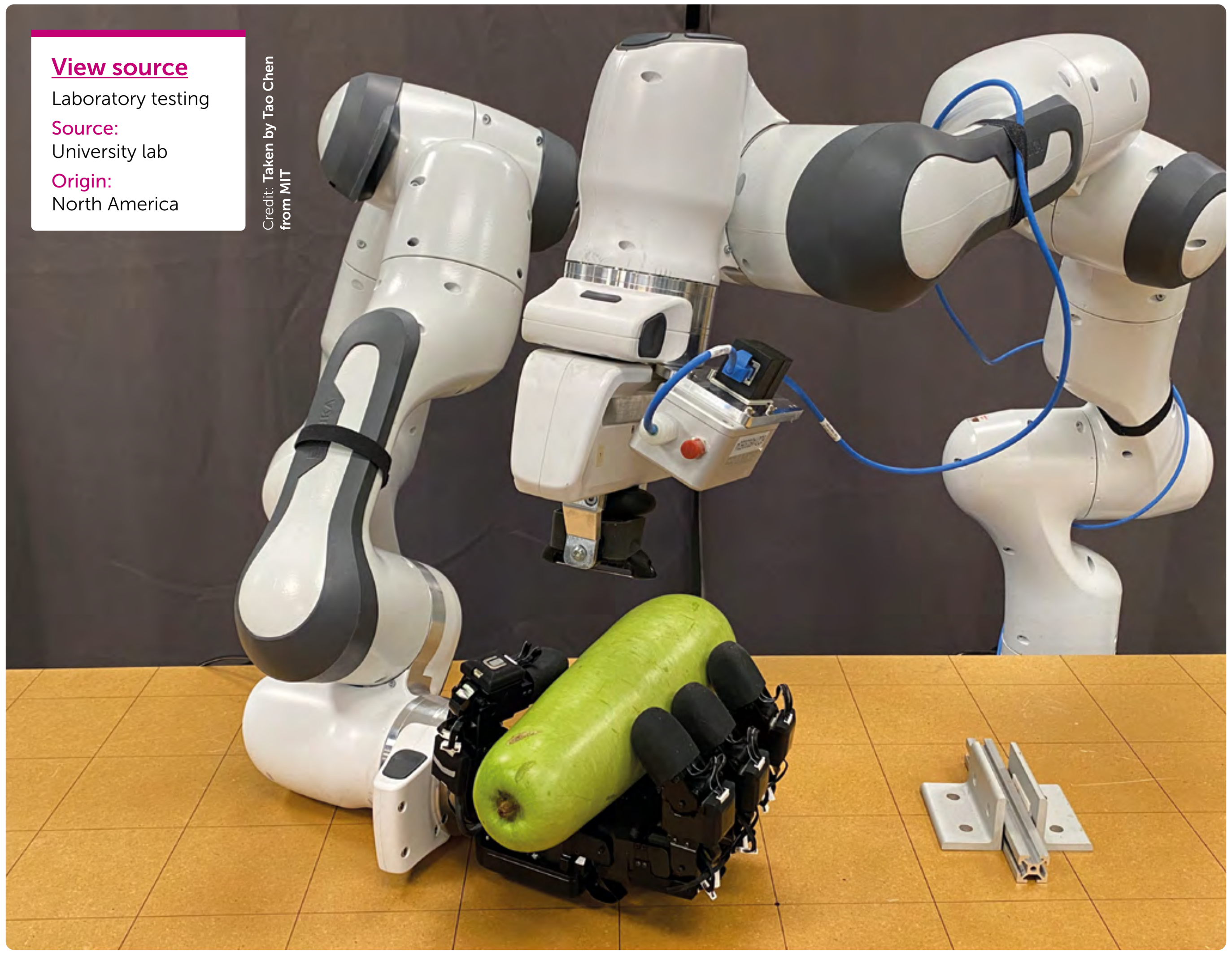
Context

- Columbia University (US) has also developed a proof-of-concept dexterous robotic hand which is trained via reinforcement learning.
- Researchers at the University of Bristol (UK) have developed a 4-fingered robot with artificial tactile 'fingertips', designed to mimic the structure of human skin.
- Google DeepMind (UK) has released an AI platform, 'Aloha Unleashed', to improve robotic dexterity in two-armed manipulation tasks. It recently demonstrated this platform by teaching a two-armed robot to lace a shoe.

What's next

Currently, MIT's robot uses only proprioceptive feedback (knowledge of its own internal state), but the researchers suggest the robot's performance could be enhanced with visual or tactile sensors.

Further reading
Watch the robot peel a courgette



View source
Laboratory testing
Source:
University lab
Origin:
North America

Credit: Taken by Tao Chen from MIT

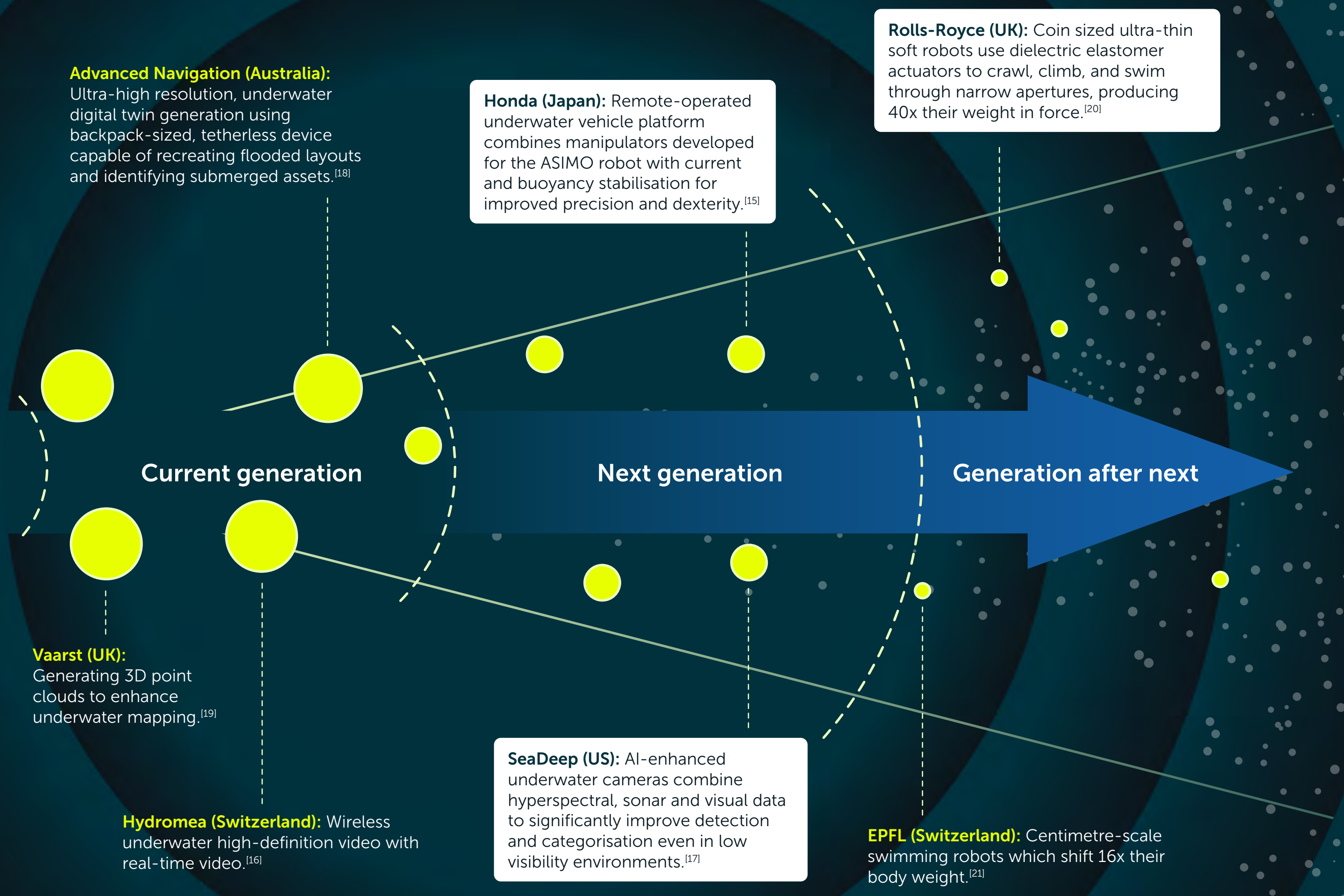
Waterborne robotics

Submersible robotics are revolutionising underwater mapping, with future AI enhancements allowing precise tasks and seamless land-water transitions for hazardous environments.

Business Horizon
Current-generation technology, in the market and available to buy.

Engineering Horizon
Next-generation technology, in field testing with a clear path to market.

Scientific Horizon
Generation-after-next technology, in laboratories and early stage prototyping.



What to look out for?

0–5 years
Commercially available tetherless robots for submerged and flooded environments provide high-resolution digital twins and real-time video for rapid, precise decision-making. Their capability to generate sub-millimetre precision 3D point clouds enhances underwater defect detection and navigation. Advances in optical communication technology are enabling seamless, tetherless video transmission underwater, further improving operations.

5–10 years
A step-change in visualisation tools revolutionises submerged landscape mapping and defect detection, addressing challenges like low-light and poor visibility. Robots now feature synchronised arm-body capabilities, offering greater dexterity in underwater environments. This precision enables complex tasks like crack sealing and asset recovery, advancing control in hazardous submerged infrastructure repairs.

10–20 years
Centimetre-scale submersible robot swarms become standard for underwater inspections, autonomously performing tasks and moving objects far exceeding their weight. Their ultra-thin designs allow them to navigate confined spaces, enabling faster, continuous repairs of cracks and leaks. Multi-domain robots, as small as a few millimetres, can crawl, climb, and swim through industrial infrastructure and storage ponds, providing real-time inspection and radiation monitoring data.

Credit: Advanced Navigation

Backpack-sized, low-cost AUV automates underwater mapping

What's the innovation
Inspecting underwater infrastructure such as pipes or storage tanks is often expensive, with traditional remote-operated vehicles (ROVs) being bulky and costly to run. Enter Hydrus, a backpack-sized, tetherless autonomous underwater vehicle (AUV) developed by Advanced Navigation (Australia). Hydrus, which weighs 7kg can dive to 300m depth, and is untethered to allow exploration without risk of entanglement, dramatically reducing the time and cost of underwater mapping and surveying.

How it works
- The AUV uses a tightly integrated combination of sonar, inertial navigation, acoustic, and optical systems for navigation and communication to enable fully autonomous underwater missions.
- The drone hosts a 4K camera, lighting and AI image processing, to capture high quality video, and can create 3D RGB point clouds by combining imagery with sonar and navigation data.
- Advanced Navigation claims the AUV can perform AI-based identification and classification of imagery onboard, though it requires extensive model training and underwater datasets.

Context
- Hydrus was recently demonstrated to have mapped and captured high-definition footage of a shipwreck off the west coast of Australia, at a cost of 75% less than typical underwater surveys.
- Custom software can be integrated into the Hydrus platform, offering the opportunity to utilise onboard cameras, sensors, and navigation data for new machine vision and AI applications.
- Startup Arkeocean (France) recently unveiled Lelantos, a 70cm micro-AUV that can perform underwater inspection in swarms.

What's next
Advanced Navigation recently opened a new facility in Australia to scale up manufacture of their AI-based navigation system for GPS-restricted environments.

View source
For sale
Source: Corporate R&D
Origin: Australasia

Further reading
Read how Hydrus AUVs are being used to promote sustainable aquaculture

View source
For sale
Source:
Startup
Origin:
Europe

Optical communication brings high-res video link to untethered underwater vehicles

What's the innovation

Underwater remotely operated vehicles (ROVs) are typically tethered to the surface via wires, which allow for real-time control and high speed data transmission, but limit range. Autonomous underwater vehicles roam freely but use acoustics to communicate, which limits data transfer. Earlier this year, Hydromea (Switzerland) unveiled a miniature, tetherless ROV that uses optical communications for high speed underwater data transfer rates, enabling live HD video transmission without a wire to surface, which could be useful for surveying underwater infrastructure such as reactor cooling systems or waste storage tanks.

How it works

- The ROV uses a proprietary optical modem, called LUMA, which converts data into light pulses. Signals can be transmitted over a range of up to 75m underwater, at 10Mbps, and even in the presence of other light sources.
- Hydromea claims the system offers 1000x greater bandwidth than acoustic communications, enabling real-time HD-quality video transfer wirelessly through water.
- The LUMA modem reportedly consumes 1500x less energy than the fastest commercially available acoustic modem per bit of data.

Context

- Removing the need for tethering cables to achieve sufficient communication bandwidth would allow operators to use live video from underwater ROVs to navigate complex confined spaces.
- Greensea IQ (UK) is trialling an untethered ROV, using a 32 kg VideoRay ROV equipped with an acoustic modem for data transfer.
- EvoLogics (Germany) specialises in underwater communication and positioning systems, offering solutions like the S2C R series, a compact underwater acoustic modem for precise positioning.

What's next

Hydromea's EXRAY ROVs and separate LUMA modems are available for purchase, with a modular design that allows LUMA to be adapted for different sensors and payloads.

Further reading
Read more about Hydromea's LUMA technology

Real-time 3D mapping for underwater inspection of pipes and storage containers

What's the innovation

Many spent fuel ponds contain structures like storage racks, pipes, and waste that has been submerged for decades, with a lack of clarity on exact locations. 3D maps of these complex environments could help track the condition and positioning of waste, and enable subsequent inertial navigation should visibility deteriorate. To accurately characterise underwater environments, Vaarst (UK) has developed an underwater 3D mapping system. The company claims it is the first to automatically generate underwater 3D point cloud models with sub-millimetre precision in real-time.

How it works

- Vaarst's SubSLAM X2 stereo-vision system claims to capture 'unmatched' 4K imagery and video, and has AI capability to remove unwanted objects from captured images.
- This system uses collected image data to create 'digital twin' 3D models of complex underwater structures to sub-millimetre precision and with accurate relative positioning.
- Models are compared between inspections to identify and monitor structural changes over time. Data can be live streamed to anywhere in the world, enabling real-time assessment and remote manipulation.

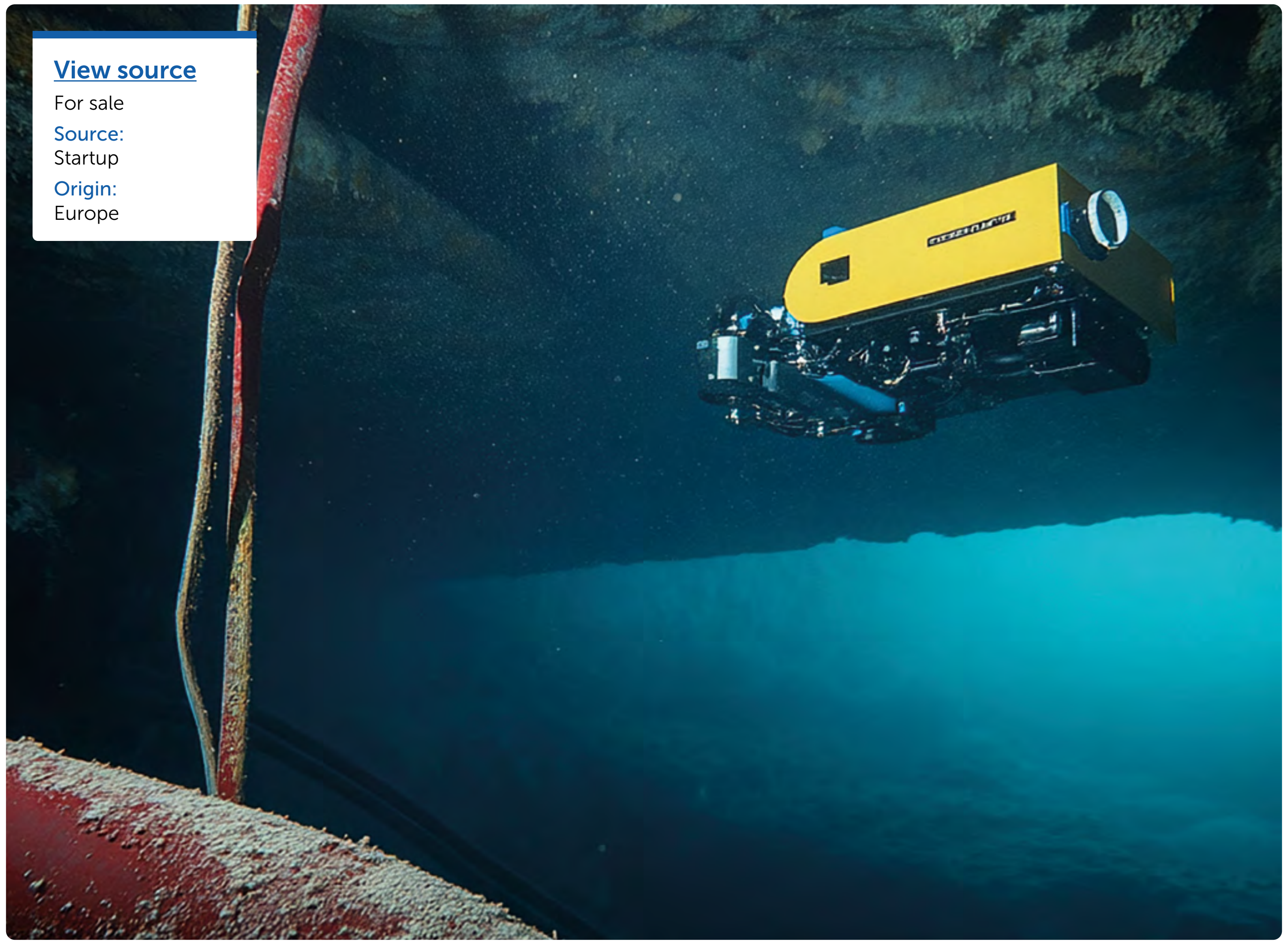
Context

- Similarly, Kraken Robotics (Canada) has developed the KATFISH, an intelligent towed sonar system, which provides ultra-high resolution seabed imagery for underwater inspections.
- Aditech's (US) Echologger DL3S is an underwater data logger that can collect data without external connections.
- Blue Atlas Robotics' (Denmark) Sentinus ROV is also capable of producing 3D reconstructions, but is not live-stream capable so cannot carry out live inspections.

What's next

While SubSLAM X2 was originally developed for the oil & gas sector, Vaarst plans to expand the application of SubSLAM into other industries including asset integrity monitoring, decommissioning, defect analysis and salvage.

Further reading
Read more about this robot's technical capabilities



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For sale
Source:
Startup
Origin:
Europe

Unmanned underwater vehicle with human-like grip for precise maintenance tasks

What's the innovation

Manipulating objects underwater can be challenging, particularly when robots need to overcome currents, changing buoyancy, and unexpected collisions. To address this, Honda (Japan) has developed a remotely operated vehicle (ROV) that combines object manipulation capabilities, originally developed for its humanoid robots, with underwater mobility.

How it works

- The technology builds on the movement and gripping mechanisms developed for Honda's humanoid ASIMO robot, to move the arms and body as one using cooperative control.
- A buoyancy model is used to keep the posture of the robot correct by moving a buoyancy material within the robot to maintain posture, even if the centre of gravity is disrupted.
- Automated movement correction allows for easier operation of the ROV and better control of object picking up and handling.

Context

- The majority of underwater technologies employ thrusters to achieve stability, which come with a slight time delay between the disruptive movement and the responding thrusters kicking in. This also contributes to the disruption of the pond bed, reducing visibility.
- Currently Saab Seaeye's (Sweden) Tiger ROV is used in Sellafield's spent fuel ponds, and is able to withstand the high alkalinity and radioactivity.
- QinetiQ (UK) develops underwater robotic systems for various applications such as inspection of submerged structures.

What's next

Honda is improving the operation of the ROVs as well as utilising aerodynamic technologies and a compact low resistance body to improve cruising speeds in harsh conditions (0.93m/s even in water currents of 1.03m/s).

Further reading

Watch the ROV in action: Read more about Honda robotics

View source

Real world testing

Source:
Corporate R&D

Origin:
Asia

AI combines visual, sonar, and hyperspectral imaging for underwater visibility

What's the innovation

Low underwater visibility, caused by disrupted silt for example, can make it hard to navigate and map underwater terrain or infrastructure. Startup SeaDeep (US), a spinout from Tufts University (US), has developed technology that combines data from multiple underwater sensors, then uses onboard AI to produce high quality images in real-time, even in poor visibility, providing pixel-level detail on substances like biofouling, marine growth and corrosion. The system has already been used to detect rust in underwater tanks.

How it works

- SeaDeep collects and integrates hyperspectral, sonar and visual (RGB) data using sensor fusion.
- The data is fed into an algorithm which processes the visual image to restore colour, improve low light conditions and remove marine snow (a shower of falling organic matter), all in real time.
- The resulting high quality images and video can support the development of 3D models of underwater environments, and be used to characterise underwater infrastructure.

Context

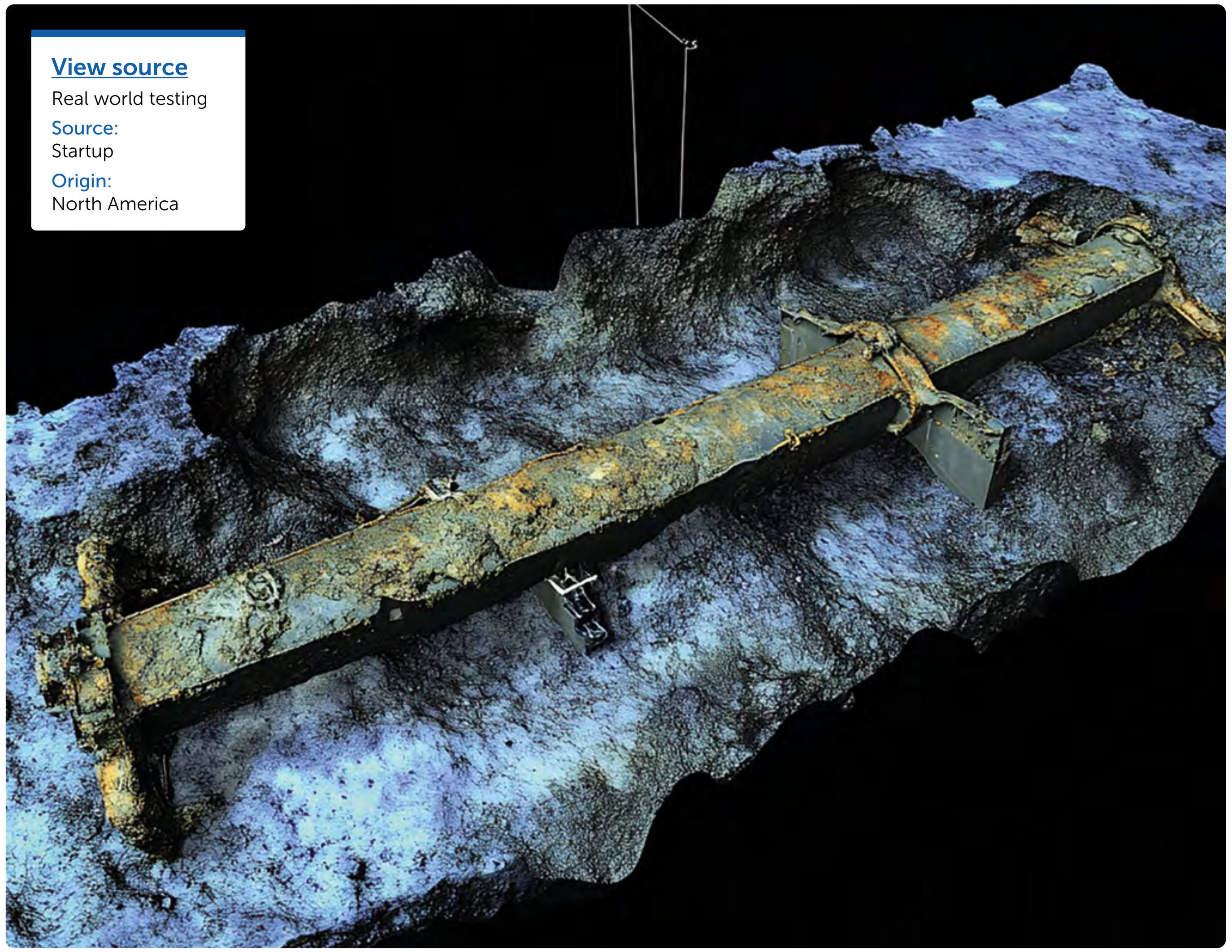
- Whereas most low-visibility images captured underwater are sharpened manually, the integration of AI into sensors allows immediate improvement of image quality.
- FullDepth (Japan) produces underwater surveying and inspection drones that also utilise ultrasound to assist navigation where visibility is poor. Images captured by drone cameras are converted to HDMI signals prior to transmission for subsequent processing.
- Other techniques for improving visibility include integrating sonar systems into underwater drones such as those produced by Deep Trekker (Canada).

What's next

The technique is planned to be used for the Seabeds 2030 project, which will attempt to map the entire global ocean floor by 2030.

Further reading

Read this case study to learn more about underwater ROVs



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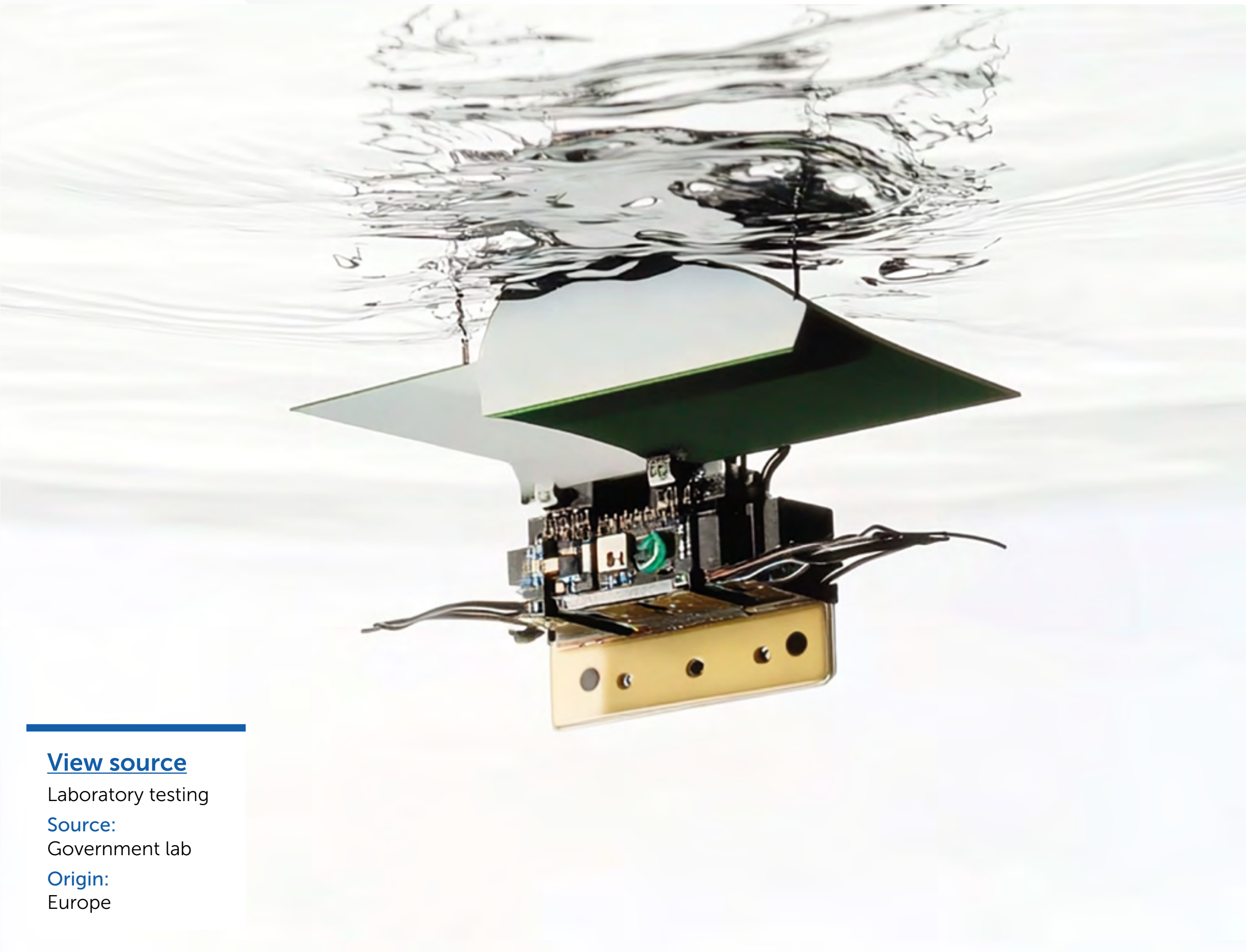
Real world testing

Source:
Startup

Origin:
North America



View source
Laboratory testing
Source:
Government lab
Origin:
Europe

Centimetre-scale autonomous flat surface swimming robots can inspect narrow openings

What's the innovation

Small robots that swim on the water's surface have the advantage of continuous communication and permanent operation thanks to solar or light harvesting. They could be used for making ongoing measurement of fuel ponds or inspecting partially submerged pipes and apertures. To do so they must be able to navigate surface environments that can be cluttered with debris such as fallen leaves and other plant based matter. This is exactly the problem solved by researchers at the Federal Institute of Technology Lausanne (EPFL, Switzerland), who have developed a swimming robot capable of fitting through 5cm apertures with a unique flat design, with autonomous, untethered operation and high manoeuvrability.

How it works

- The robot is inspired by marine flatworms, and floats on the water using surface tension.
- It generates electrical excitations that move 0.5mm thick undulating pectoral fins, similar to those found on fish, to generate forward propulsion.
- The fin propulsion system enables strength and agility, allowing the robot to push 16x its body weight while travelling with a speed of 5.1cm/s and 195°/s rotation.

Context

- Existing centimetre scale aquatic robots are typically tethered to an external power supply or have poor manoeuvrability, limiting their applicability to inspection. Tethys Robotics (Switzerland) builds miniaturised underwater robots capable of being deployed in rough water conditions, using acoustic sensors for navigation.
- Eelume (Norway) has developed snake-like robots for subsea inspection and maintenance, showcasing how flexible designs can enhance manoeuvrability.

What's next

The authors believe the approach of electrohydraulic actuators for undulatory propulsion, combined with solar panels to extend operational lifetime, will facilitate continuous environmental monitoring by fleets of small aquatic robots.

Further reading
Read about micro-robots the size of grain of rice

Coin-sized soft robots can explore small spaces on land and underwater

What's the innovation

Safety-critical industrial environments need regular inspections across the facility for issues like corrosion or blockages. Areas that need checking can include small millimetre-sized gaps, some of which are high up or submerged. To provide a solution, the Rolls-Royce University Technology Centre at the University of Nottingham (UK) has developed a new class of ultra-thin, soft robots which can crawl, climb, and swim to navigate narrow spaces. In tests the robots have already traversed and inspected the narrow air gap between the rotor and stator of a generator, which is inaccessible for conventional robots.

How it works

- The soft robots' design uses dielectric elastomer actuators: polymers which experience changes in thickness and length when an electric voltage is applied, allowing linear or undulating movement.
- The robots are only 1.7mm thick, roughly the size of a coin, and exhibit output force over 40x their weight, and travel at over one body length per second.
- The robots can operate on solid surfaces or, when submerged and joined together, can transition between horizontal and vertical surfaces.

Context

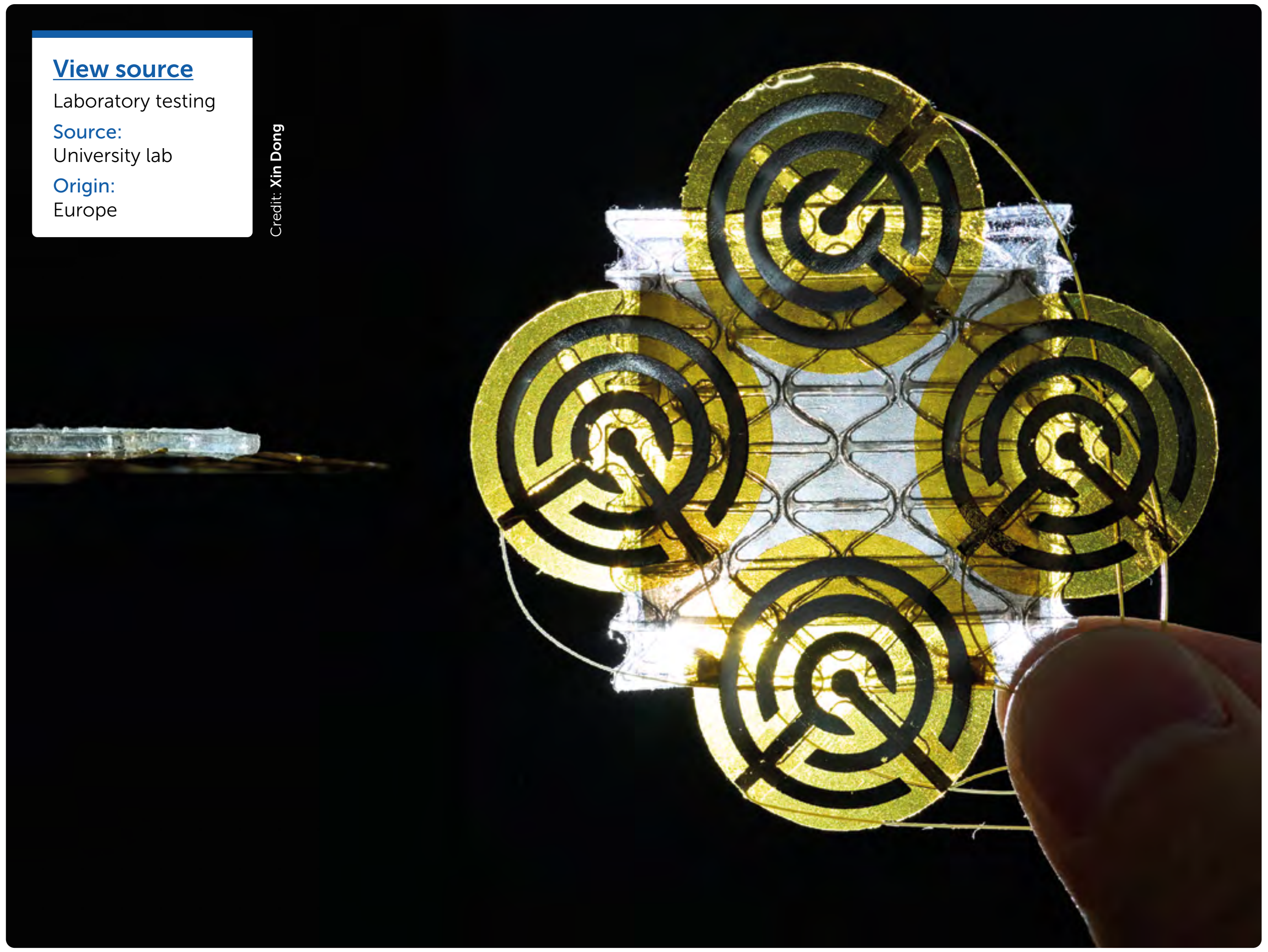
- Robots for accessing small and confined spaces, such as worm-like soft robots, typically move in one direction. Combining multiple locomotion modes enables robots to move through spaces containing multiple obstacles and within liquid and even aerial domains.
- Researchers at Northwestern University (US) recently developed a soft flexible robot that was demonstrated to crawl through pipe systems.
- The University of South Carolina (US) has also developed miniature, hydraulic actuators which can control robots less than a millimetre thick.

What's next

Currently, Rolls-Royce's soft robots are tethered to a controller via wires, but the researchers suggest the robots' range and function could be improved by exploring a battery-powered design to create a tetherless system.

Further reading
Read more about Rolls-Royce's robotics research

View source
Laboratory testing
Source:
University lab
Origin:
Europe



Credit: Xin Dong

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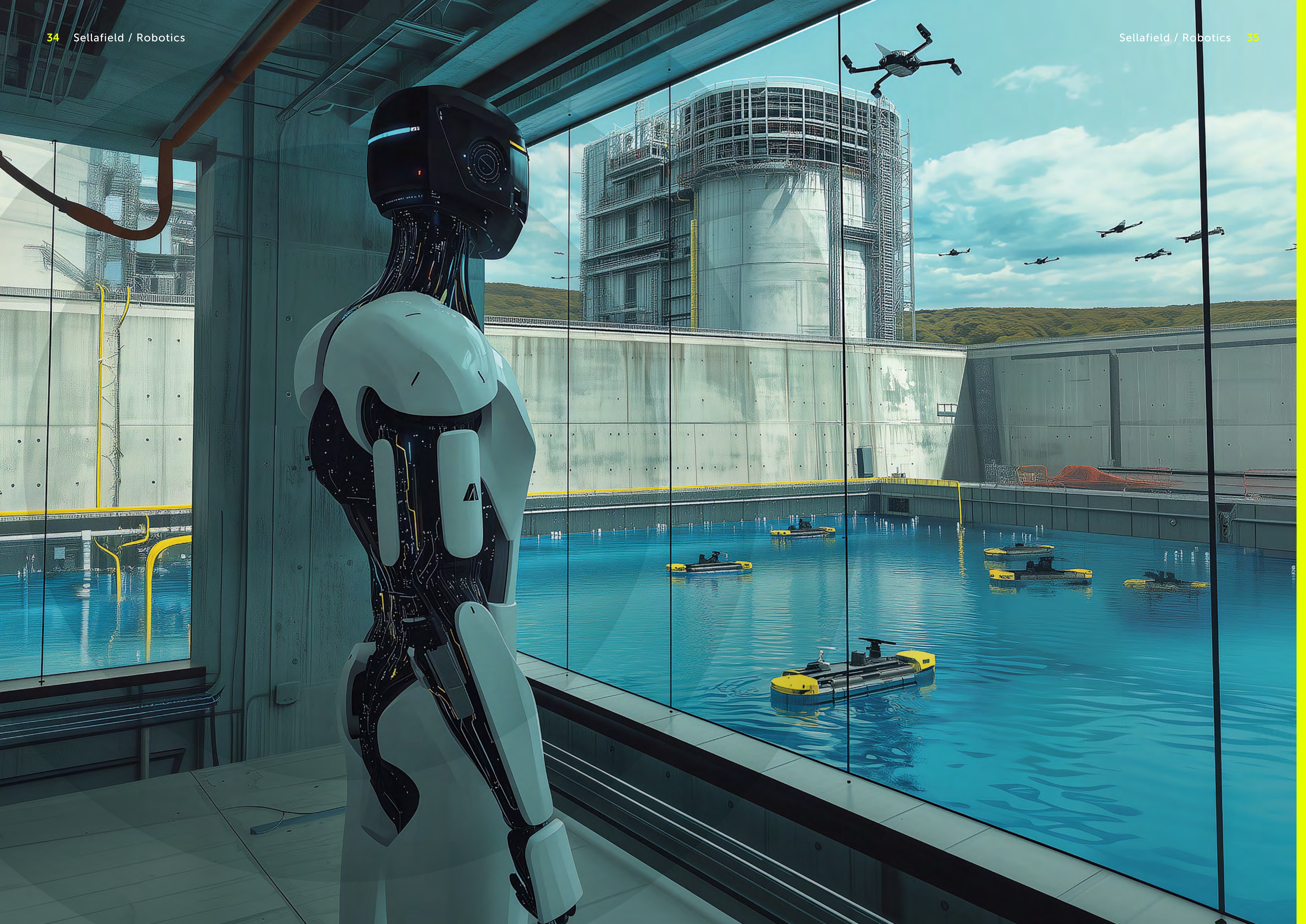

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