Robotics and the Blue Economy:

Sustainable Growth in the Ocean Space

1. Introduction

This short paper has been prepared to introduce the topic of Robotics and the Blue Economy: Sustainable Growth in the Ocean Space, which is the chosen theme of the 2026 European Robotics Forum (ERF). This large annual event brings together experts from research and industry from across Europe to share ideas, create new connections and celebrate the best of robotics, one of the most important technologies that will shape the future of society for generations to come. The chosen theme reflects the specific setting for ERF 2026. Stavanger, Norway has been shaped by its maritime position, developing from a Viking trading settlement to become a major centre for fishing and related industries, shipping and shipbuilding and today the onshore hub for North Sea oil and gas and a tourist destination. Stavanger's links with robotics span more than half a century. The Trallfa robot was developed here during the 1960s and became the world's first commercial, electrically-powered industrial spray-painting robot. Specific to our ocean theme, underwater robots and drones are commonly used for sustainable ocean management, such as monitoring aquaculture facilities, as this paper covers later.

2. The Ocean Space and the Blue Economy

The 'ocean space' is a broad term used to describe the entire marine environment, including the sea surface, the body of water, the seabed, and the coastal areas. It also refers to activities and industries operating in the ocean, including aquaculture, offshore energy (wind/oil/gas).

As with all physical environments the ocean space is subject to overlapping or competing priorities. It can be seen as a 'container of resources' for human exploitation, a space used for strategic national interests, a natural environment to be preserved, and a shared medium for the pursuit of these multiple goals. Taking all of these together, the oceans are increasingly viewed as a unified space needing active management to ensure their sustainability.

The ocean space is therefore a source of opportunity and solutions for many national, international and global challenges. However, by its very nature it is also a challenging environment, one that can only be accessed by humans with varying degrees of difficulty. Over millennia, human ingenuity has found solutions to protect humans in the oceans, to enable us to explore the marine environment and then to harvest what humankind has discovered within the ocean's depths.

Archaeological research cited by the British Library points to evidence of fishing by humans (specifically humans eating shellfish) that dates back 164,000 years, while more complex fishing methods involving hooks extend back to at least 40,000 years ago. In the ocean space as in all other environments, the use of tools or technology continues to transform human capability to interact with the natural environment. The relationship has not always been benign and human exploitation of oceanic resources can lead to damage and harmful alterations to the ecology.

Human exploitation of the ocean space to date over millennia has been successful in extracting great value – from trading and transport to fisheries and fossil fuel extraction – but at considerable cost, not just to human life but to the ocean environment itself. This activity cannot pass 'unnoticed' by the environment in which it takes place. It has many consequences for the condition of the ocean environment and for the many forms of life which rely on it as well as for our own. And yet, as we shall see, robotics offers a variety of solutions to monitor the health of the ocean space and actively to alleviate, minimise and in some cases reverse negative effects of our human presence in the ocean space.

The United Nations has set a specific goal for the ocean space within its 17 goals for sustainable development: Conserve and sustainably use the oceans, seas and marine resources for sustainable development. In its text on ocean sustainability, the UN argues that for the oceans to contribute to human well-being, the marine ecosystem has to be protected by avoiding causing serious or irreversible harm. This can be done through a more sustainable use of resources, changes in production and consumption patterns, improved management and control of human activities through good governance.

Symbol for the UN Sustainable Development goal 14

The primary challenge can be summarised this: how can humanity continue to derive increasing benefits from the ocean space – notably food for growing populations – sustainably, without irreversibly damaging the ocean environment, by reducing the exploitation of the oceans' resources and by preserving and over time restoring the health of the ocean space. In this sense, we need to stop biting the hand that feeds and achieve more with less impact. That's a clear challenge – and one for which robotics provides some solutions.

3. The oceans and Norway

The ocean is of vital, foundational importance to Norway. It serves as a cornerstone of its economy, culture, and national identity. With a coastline over 100,000 km long and an ocean area six times larger than its landmass, Norway has access to vast marine resources. These circumstances bring both material advantages and also responsibilities for the stewardship of the ocean space.

Ocean-based industries—fisheries, aquaculture, shipping, and offshore oil/gas—account for a massive share of Norway's export revenues, often estimated around 70%. Oil and gas alone constitute a significant portion of its GDP.

Norway is a world leader in fisheries and aquaculture, particularly as a top exporter of farmed salmon. Norway is the world's 3rd largest exporter of fish.

The ocean is also key to the greening of Norway's economy, with major investments in offshore wind, carbon capture and storage (CCS) beneath the seabed, and green shipping technology.

Norway's maritime jurisdiction includes vast areas of the Arctic, making it a key actor in managing resources, environmental protection, and security in the High North.

Norway is exploring new ocean industries, including deep-sea mining for critical minerals (cobalt, copper) for batteries, though this is subject to environmental debate.

Over 80% of Norway's population lives within 20 km of the coast. This proximity anchors the country's culture in maritime traditions and the ocean provides jobs for hundreds of thousands of people.

With the ocean central to its welfare, Norway focuses on 'integrated ocean management', aiming to balance sustainable production with the protection of marine ecosystems. According to WWF Global Arctic Programme, through its management plan system, Norway is implementing an ecosystem-based approach to managing human activities that affect the marine environment.

4. Sustainable growth in the ocean space – perspectives

The 2026 European Robotics Forum is organised and hosted by NORCE and SINTEF Norway's leading research institutes in partnership with euRobotics, the European robotics association. In this next section the partner organisations each explain the role that robotics can and does already play in the blue economy from their individual perspectives.

4.1 Robotics in the blue economy – the NORCE perspective

Robotics is emerging as a critical technology for the future of the European Blue Economy. Over the next decade, autonomous and remotely operated systems will transform how ocean resources are monitored, managed, and utilized. These technologies will play a critical role in offshore renewable energy, autonomous shipping, aquaculture, environmental monitoring, and subsea infrastructure maintenance. Norway is uniquely positioned to lead this transformation. With its advanced maritime industries, strong research institutions, and proactive regulatory authorities, the country has developed one of the world's most mature ecosystems for ocean robotics. Organizations such as NORCE Research, NTNU, SINTEF Ocean, and the Institute of Marine Research collaborate closely with companies including Kongsberg Maritime, Equinor, and Reach Subsea to develop and deploy new robotic ocean technologies. Here we outline the strategic role robotics will play in the EU Blue Economy over the next decade, highlighting

Norway's innovation ecosystem and the contribution of NORCE Research to the development of a sustainable, data-driven ocean economy.

Robotic technologies will influence multiple sectors of the Blue Economy:

Offshore renewable energy: The expansion of offshore wind farms, subsea cables, and future hydrogen infrastructure will require continuous inspection and maintenance. Autonomous subsea robots can conduct these operations more efficiently than traditional vessel-based interventions.

Maritime transport: Autonomous and remotely controlled vessels are expected to transform short-sea shipping and coastal logistics. Robotic navigation systems, sensor fusion technologies, and AI-assisted vessel control will enable safer and more efficient maritime transport.

Environmental monitoring: Continuous observation of marine ecosystems is essential for sustainable ocean management. Robotic sensor platforms can collect oceanographic and ecological data at scales previously impossible with traditional research vessels.

Aquaculture: Robotics are increasingly used in aquaculture operations for automated feeding, net cleaning and inspection, fish health monitoring, seabed monitoring under cages, slaughter facilities, and many operational events. Future offshore aquaculture systems will rely heavily on robotic monitoring and maintenance technologies.

Subsea infrastructure: Europe's growing subsea infrastructure network—including communication cables, energy pipelines, and carbon storage systems—requires robotic inspection and intervention capabilities to ensure reliability and environmental safety.

Norway's long-term ocean policy is articulated in national ocean strategies such as the government's ocean strategy, 2021, **"Blue Ocean, Green Future"** and related policy documents developed by the Ministry of Trade, Industry and Fisheries. These strategies emphasize the importance of research, innovation, and technology development to ensure sustainable growth in ocean industries. Ocean industries represent a significant share of Norway's economy, including maritime transport, offshore energy, mineral activities on seabed, fisheries, and aquaculture. National policy highlights the importance of digitalization, automation, and advanced technologies to maintain Norway's global leadership in maritime and ocean industries. The Norwegian innovation model emphasizes collaboration between industry, research institutions, and government agencies. This "triple helix" system supports technology development, testing, and commercialization of new ocean technologies. Robotics, artificial intelligence, and digital monitoring systems are therefore considered key enabling technologies for the future competitiveness of Norway's ocean economy.

The **Maritim21 strategy** provides national guidance for research and innovation priorities in Norway's maritime sector. The strategy aims to strengthen Norway's position as a world-leading maritime nation through leadership in green technologies and digital maritime systems. Priority technology areas identified in Maritim21 include autonomous vessels, maritime digital infrastructure, sensor technologies, remote operations, and automation. These areas directly support the development of marine robotics and autonomous ocean systems. The strategy highlights the importance of collaboration between research institutions, maritime companies, and public authorities to accelerate innovation and commercialization of new technologies. Through coordinated research investments and industry partnerships, Norway aims to develop maritime solutions that combine sustainability, digitalization, and automation.

Norway has developed one of the world's most advanced ecosystems for marine robotics innovation. Research institutions such as NORCE Research, NTNU, SINTEF Ocean, and the Institute of Marine Research contribute to the development of ocean observation systems, autonomous vehicles, and marine sensor technologies. Norwegian companies are global leaders in subsea robotics and maritime automation. Kongsberg Maritime develops advanced underwater vehicles, navigation systems, and marine sensors used worldwide. Energy company Equinor supports robotics development for offshore energy infrastructure, while companies such as Reach Subsea and Eelume specialize in subsea robotic inspection and maintenance. Public authorities also play an important role. The Norwegian Maritime Authority supports regulatory frameworks for testing autonomous vessels, while the Research Council of Norway funds national programs in ocean technology and digitalization.

This collaborative ecosystem enables rapid innovation and deployment of new robotic technologies for ocean industries.

NORCE Research plays a central role in Norway's ocean technology landscape through interdisciplinary research in marine science, aquaculture, energy systems, and digital technologies. The institute contributes to the development of integrated ocean monitoring systems, combining robotic platforms, drones, environmental sensors, and digital modelling tools.

These technologies support ecosystem monitoring, climate research, and sustainable ocean management. NORCE also contributes to the development of digital twins of the ocean. These systems integrate observational data, satellite information, and predictive modelling to simulate marine environments and support decision-making in ocean governance. NORCE contributes to the development of most of the European Blue Economy sectors. In addition to research activities, NORCE coordinates the European Digital Innovation Hub Oceanopolis. Oceanopolis supports small and medium-sized enterprises developing advanced digital and robotic technologies for ocean industries. Through Oceanopolis, companies gain access to test facilities, artificial intelligence expertise, high-performance computing resources, and innovation advisory services. This support helps SMEs prototype, test, and scale robotics solutions for offshore energy, aquaculture, maritime transport, and environmental monitoring.

By 2035, the Blue Economy will likely rely on large networks of autonomous robotic systems operating across the ocean environment. Fleets of underwater robots may continuously map seabed conditions and monitor offshore energy installations. Autonomous surface vessels could support environmental monitoring and maritime logistics. Smart aquaculture systems may operate with minimal human intervention using AI-driven robotic monitoring and operational technologies. For Norway, this transition represents both an economic opportunity and a responsibility. The country's leadership in maritime technology places it in a strong position to export ocean robotics solutions globally while supporting sustainable ocean governance. Research institutions such as NORCE will play an essential role in ensuring that technological innovation aligns with environmental sustainability and responsible resource management.

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4.2 Robotics and the BLUE economy – the SINTEF perspective

Global food demand is rising amid population growth, while progress on food security and nutrition remains too slow due to various aspects (1). The aquatic food systems are increasingly recognized as vital for food and nutrition security, and they are characterized with a low environmental footprint, great diversity and capacity to supply critical nutrients to sustain healthy diets (1). The growth in aquatic food and protein supply is expected to come primarily from sustainable aquaculture growth and from effective fisheries management (1). More broadly, recent work on robotics and AI in agriculture argues that these technologies will be increasingly important for closing future food gaps, improving resilience to labour shortages and climate-related disruptions, and strengthening the capacity of food systems to deliver nutritious food, and increase food sovreignity (2, 3, 4, 28). Likewise, in aquatic food systems, effective management of fisheries combined with rapidly expanding sustainable aquaculture will be essential to provide adequate nutrition, support livelihoods, and achieve multiple Sustainable Development Goals in a world of projected 8.5 billion people by 2030 (1).

Robotics is a powerful enabler of the blue economy and of progress toward sustainable development goals (1) and is increasingly regarded as a technology with significant disruptive potential for food production and food security in general (1, 3, 4, 5, 6, 7). Beyond its sector-specific applications, robotics can contribute to more resilient food systems by addressing labour constraints, improving precision and productivity, supporting better monitoring and decision-making, and helping value chains adapt more effectively to uncertainty and disruption (3, 4, 5, 6, 7). This is particularly relevant in light of recent experience showing that higher degrees of automation can also strengthen the resilience of food production and processing systems by reducing vulnerability to labour disruptions, crisis situations, and operational restrictions (8). In aquaculture, robotics can enable more precise, scalable, and welfare-oriented production across the value chain, spanning autonomous inspection and monitoring systems in sea-based farming operations and robotic manipulation in land-based processing, especially in tasks involving challenging deformable raw materials characterized by high biological variation and requiring advanced perception, dexterity, and adaptive control (9, 11, 27). In fisheries, the role of robotics is seen in adding value to sustainable harvesting and effective management, improve the efficiency of catch processing, automate onboard handling and land-based processing, and strengthen monitoring and management through better data and autonomous operations (1). In this sense, FAO's *State of World Fisheries and Aquaculture* and OECD's Report broadly frames digital automation, AI, and robotics as technologies that can help address labour constraints, improve precision, and support productivity when adopted appropriately (1, 10).

This is particularly important for high-cost aquatic food producing countries such as Norway and other European nations, where increased robotic automation can reduce production costs, strengthen the economic viability of local processing, limit the outsourcing of value-added activities to low-cost countries, and reduce emissions by shortening transport-intensive value chains (1, 7). At the same time, robotization is likely to shift competence needs, increasing demand for expertise in automation, robotics, ICT, and other enabling technologies (1, 25). In this perspective, robotics should be understood not merely as an operational improvement, but as a strategic enabler of competitiveness, domestic value creation, sustainability, and blue transformation (1, 3, 4).

Robotics can for example add value in these stages: 1) Precision feeding: automated feeding systems and AI- and sensor-based control can reduce feed waste, since feeding is one of the largest operational costs (25); 2) Monitoring and early detection: cameras, underwater drones, and automated sensing can detect and track fish behavior, growth, detect lice, mortality, and inspect net integrity promptly (16, 18, 27); 3) Welfare operations: robotics can support delousing, net cleaning, inspection, and handling tasks that are repetitive, risky, or hard to do consistently manually (15, 16, 18); 4) Processing: robotics in salmonid slaughtering, grading, filleting, packing, quality control, and other advanced processing tasks such as cutting can improve inspection consistenty and production yield across the processing stage of the value chain (11, 17, 20, 22).

In the aquaculture farming and processing stages, tasks such as inspection, maintenance and repair of nets (18), or fish slaughtering, cutting(11), grading(12, 19), post-trimming (20), packing, and quality control(12), require highly advanced inspection, manipulation skills, and dexterity for robots, a capability that they currenty don’t have (21, 22). Net maintenance and repair involve the manipulation of large, flexible and deformable structures composed of intertwined fibers, requiring robots to perform precise inspection, localization of damage and dexterous manipulation of complex mesh geometries (18). Likewise, handling fish during processing operations such as cutting, grading and processing requires interaction with biological materials that are highly variable, fragile and slippery, posing significant challenges for reliable robotic perception, grasping and manipulation (11, 22, 26). In particular, fish and other seafood raw materials are characterized by high biological variation, as they differ in size, shape, texture, surface conditions, slipperiness, and rigidity while also changing dynamically during handling and processing, such as in the case of fillets or loins (13, 14, 17). This creates a high level of uncertainty that challenges conventional robotic systems based on fixed motion planning, structured environments, and rigid-body assumptions (11, 13, 14, 17). **To address these conditions, there is a growing need for fundamentally new robotic capabilities in perception, control, learning, and dexterity (11, 21, 22, 26)**. In this context, the paradigm of **Physical AI** becomes particularly relevant for the potential of robotics in the blue economy (23, 24). Physical AI refers to intelligent systems that perceive, decide, and act directly in the physical world through continuous interaction with the environment and real-world objects. The World Economic Forum frames Physical AI as a new generation of industrial automation in which intelligent robotic systems combine perception, reasoning and action to operate with greater autonomy, flexibility and adaptability in increasingly complex and uncertain operational settings (24). In the blue economy, this makes Physical AI relevant not only for advanced robotic manipulation, but also for strengthening the resilience, competitiveness and scalability of aquatic and non-aquatic food production, processing and logistics systems (19).

For fisheries, robotics can support the sustainable use of wild resources by improving how fisheries are effectively monitored, harvested, processed and managed (1). In high-cost countries such as Norway, where labour and production costs are high, robotics is particularly important as an enabler of improved productivity, profitability and industrial competitiveness (1). For example, in whitefish and pelagic fisheries, higher levels of automation can reduce production costs, stabilize processing capacity, and make it more economically viable to perform value-added processing closer to harvesting sites rather than exporting raw materials to low-cost countries for manual processing (1). This shift has several important implications. First, local or near-harvest processing helps preserve raw material quality, reduces handling time, and improves yield and product consistency. Second, it strengthens regional employment and industrial activity by retaining a greater share of the seafood value chain domestically, even in high-cost economies. Third, it may substantially reduce the climate footprint associated with transporting unprocessed fish over long distances for processing abroad (1).

Autonomous surface and underwater vehicles, drones, and sensor-rich platforms can contribute to stock mapping, environmental monitoring, route optimization and path planning, enabling more efficient fishing operations while improving the data and knowledge base for fisheries management and decision-making (1). In this way, robotics supports and enables a more intelligent and effective management and harvesting of the available biomass, more efficient processing of catches, and improved organization of seafood value chains, contributing to lower costs, higher profitability, strengthened domestic processing and reduced environmental impacts.

Alltogether, these capabilities position robotics and autonomy as important technological enablers for more sustainable, efficient and resilient aquatic food systems within the broad concept of the blue economy. As such, robotics, autonomy, and AI are projected to become indispensable to future food systems (3, 4, 7, 24) as they can help cope with labour shortages, improve precision and productivity, increase food sovereignty and strengthen resilience against disruptions such as pandemics, conflict, climate shocks, and logistics failures. In this perspective, the future of aquatic food production is likely to depend on tighter integration between human expertise, robotics, and AI across production, processing, inspection, and logistics chains.

1. FAO. (2024). *The State of World Fisheries and Aquaculture 2024: Blue Transformation in action*. Rome: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd0683en
2. FAO. (2025). *The State of Food and Agriculture 2025: Addressing land degradation across landholding scales*. Rome: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd7067en
3. FAO. 2022. The State of Food and Agriculture 2022 – Leveraging agricultural automation for transforming agrifood systems. 2022. Rome. https://doi.org/10.4060/cb9479en
4. Torero, M. (2021). Robotics and AI in food security and innovation: Why they matter and how to harness their power. In J. von Braun, M. S. Archer, G. M. Reichberg, & M. Sánchez Sorondo (Eds.), *Robotics, AI, and Humanity* (pp. 99–107). Springer. https://doi.org/10.1007/978-3-030-54173-6_8
5. Guenat, S., Purnell, P., Davies, Z.G., et al.: Meeting sustainable development goals via robotics and autonomous systems. Nature Communications 13, 3559 (2022) https://doi.org/10.1038/s41467-022-31150-5
6. King, A. (2017). Technology: The future of agriculture. *Nature, 544*, S21–S23. https://doi.org/10.1038/544S21a
7. Hodson, R. (2017). Food security. *Nature, 544*, S5. https://doi.org/10.1038/544S5a
8. Isachsen, U. J., Theoharis, T., & Misimi, E. (2021). Fast and accurate GPU-accelerated, high-resolution 3D registration for the robotic 3D reconstruction of compliant food objects. *Computers and Electronics in Agriculture, 180*, 105929. https://doi.org/10.1016/j.compag.2020.105929
9. Haugaløkken, B. A., Eilertsen, E., Føre, M., Svendsen, E., Mulelid, M. A., Sunde, L. M., & Kelasidi, E. (2026). Precision fish farming – from Industry 4.0 to Smolt 4.0. In *Seafood 4.0: Digital, Physical, and Biological Innovations from Sea to Table* (pp. 395–430). Elsevier. https://doi.org/10.1016/B978-0-443-33750-5.00015-9
10. Ryan, M. (2023), "Labour and skills shortages in the agro-food sector", *OECD Food, Agriculture and Fisheries Papers*, No. 189, OECD Publishing, Paris, https://doi.org/10.1787/ed758aab-en.
11. Herland, S., Parag, A., Øye, E. R., Zhang, F., Makiyeh, F., Lillienskiold, A., Singh, A. P., Adelson, E. H., Chaumette, F., Krupa, A., Corke, P., & Misimi, E. (2025). *Sashimi-Bot: Autonomous tri-manual advanced manipulation and cutting of deformable objects*

(arXiv:2511.11223). arXiv. https://doi.org/10.48550/arXiv.2511.11223
12. Balaban, M. O., Misimi, E., & Ayvaz, Z. (2016). Quality evaluation of seafoods. In *Computer Vision Technology for Food Quality Evaluation* (2nd ed., pp. 243–270). Elsevier. https://doi.org/10.1016/B978-0-12-802232-0.00010-4
13. Herland, S., & Misimi, E. (2025). Non-prehensile shape manipulation of elastoplastic objects with reinforcement learning. In *Proceedings of the 2025 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 13204–13210). IEEE. https://doi.org/10.1109/ICRA55743.2025.11127639
14. Misimi, E., Øye, E. R., Sture, Ø., & Mathiassen, J. R. (2017). Robust classification approach for segmentation of blood defects in cod fillets based on deep convolutional neural networks and support vector machines and calculation of gripper vectors for robotic processing. *Computers and Electronics in Agriculture, 139*, 138–152. https://doi.org/10.1016/j.compag.2017.05.021
15. Høgstedt, E. U., Schellewald, C., Stahl, A., & Mester, R. (2025). A multi-purpose tracking framework for salmon welfare monitoring in challenging environments. In *2025 IEEE/CVF International Conference on Computer Vision Workshops (ICCVW)* (pp. 2153–2162). IEEE. https://doi.org/10.1109/ICCVW69036.2025.00225
16. Føre, M., O'Brien, E. M., & Kelasidi, E. (2025). Deep learning methods for 3D tracking of fish in challenging underwater conditions for future perception in autonomous underwater vehicles. *Frontiers in Robotics and AI, 12*, 1628213. https://doi.org/10.3389/frobt.2025.1628213
17. Sivertsvik, M., Sumskiy, K., & Misimi, E. (2024). Learning active manipulation to target shapes with model-free, long-horizon deep reinforcement learning. In *Proceedings of the 2024 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE. https://doi.org/10.1109/ICRA57147.2024.10610033
18. Amundsen, H. B., Katsidoniotaki, E., Føre, M., & Kelasidi, E. (2025). Aquaculture robotics: Adaptive path planning through real-time estimation of the shape of flexible net pens. *IEEE Transactions on Field Robotics, 2*, 230–250. https://doi.org/10.1109/TFR.2025.3560245
19. Misimi, E., Erikson, U., & Skavhaug, A. (2008). Quality grading of Atlantic salmon (*Salmo salar*) by computer vision. *Journal of Food Science, 73*(5), E211–E217. https://doi.org/10.1111/j.1750-3841.2008.00779.x
20. Bar, E., Mathiassen, J. R., Eilertsen, A., Mugaas, T., Misimi, E., Linnerud, Å.S., Salomonsen, C., & Westavik, H. (2016). Towards robotic post-trimming of salmon fillets. *Industrial Robot: The International Journal of Robotics Research and Application, 43*(4), 421–428. https://doi.org/10.1108/IR-11-2015-0205
21. Zhu, J., Cherubini, A., Dune, C., Navarro-Alarcon, D., Alambeigi, F., & Berenson, D. (2022). Challenges and outlook in robotic manipulation of deformable objects. *IEEE Robotics & Automation Magazine, 29*(3), 67–77. https://doi.org/10.1109/MRA.2022.3147415
22. Singh, A. P., Romanov, D., Misimi, E., & Mason, A. (2025). Vision-based approaches for cutting food products with robots: A review. *Robotics and Autonomous Systems, 194*, 105145. https://doi.org/10.1016/j.robot.2025.105145
23. Salehi, V. (2025). Fundamentals of Physical AI. *Journal of Intelligent System of Systems Lifecycle Management, 2*. https://doi.org/10.71015/z6mc6967
24. World Economic Forum. (2025). *Physical AI: Powering the New Age of Industrial Operations*. Geneva: World Economic Forum. https://reports.weforum.org/docs/WEF_Physical_AI_Powering_the_New_Age_of_Industrial_Operations_2025.pdf
25. Måløy, H., Aamodt, A., & Misimi, E. (2019). A spatio-temporal recurrent network for salmon feeding action recognition from underwater videos in aquaculture. *Computers and Electronics in Agriculture, 167*, 105087. https://doi.org/10.1016/j.compag.2019.105087
26. Misimi, E., Herland, S., & Chaumette, F. (2026). Visual servoing-based active vision for 3D

object reconstruction. *IEEE Robotics and Automation Letters, 11*(2), 1210–1217. https://doi.org/10.1109/LRA.2025.3641435
27. Xanthidis, M., Skaldebø, M., Haugaløkken, B., Evjemo, L., Alexis, K., & Kelasidi, E. (2024). ResiVis: A holistic underwater motion planning approach for robust active perception under uncertainties. *IEEE Robotics and Automation Letters, 9*(11), 9391–9398. https://doi.org/10.1109/LRA.2024.3455893
28. *FAO (2020) Agriculture 4.0: Agricultural robotics and automated equipment for sustainable crop production*. Integrated Crop Management Series. http://www.fao.org/3/cb2186en/CB2186EN.pdf

Figure 1 non-prehensile robotic manipulation of salmon loins - the agent is trained exclusively in simulation and is deployed zero-shot to the real world. Non-prehensile manipulation alleviates the need to grasp the objects unnecessarily and, in this way, achieve the task by being gentle to the product and avoiding the quality degradation during processing stages of salmon. From: Herland, S., & Misimi, E. (2025). Non-prehensile shape manipulation of elastoplastic objects with reinforcement learning. In Proceedings of the 2025 IEEE International Conference on Robotics and Automation (ICRA) (pp. 13204–13210). IEEE. https://doi.org/10.1109/ICRA55743.2025.11127639

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4.3 Robotics and the blue economy – the role of euRobotics

The European robotics association euRobotics plays a key role in the blue economy by promoting the development, innovation, and deployment of marine robotics, AI, and autonomous systems to ensure sustainable industrial growth in maritime sectors. As the coordinator of the Europe's robotics community, the association also aligns technological advancements with the EU's goals for a sustainable blue economy, including cleaner energy, safe shipping, and responsible resource extraction. With its structure of Topic Groups that bring together roboticists and related interests around a series of theme- and sector-specific topics, euRobotics provides forums for the exchange of information and to enable collaborations that focus on key aspects of the ocean space. While there is no single Topic Group (TG) that addresses the ocean environment overall, several individual TGs are relevant to this theme, notably those focused on Sustainability, Marine, Harsh Environments, Inspection & Maintenance and even Space (with a focus on ocean monitoring by satellite).

The **Sustainability** TG bridges the gap between advanced robotic technologies and environmental stewardship, ensuring that robotic applications are both beneficial to marine ecosystems and sustainable in their own lifecycle. The group's focus underlines how robotics can solve sustainability challenges in maritime sectors—such as aquaculture, shipping, and offshore energy—while ensuring the robots themselves are designed and manufactured sustainably.

Over successive years, since 2021, the **Marine Robotics** topic group has investigated the challenges and opportunities of using autonomous systems in the oceans, involving scientists and engineers both from academia and industry. The following year the focus switched to AI, in recognition that AI offers several benefits for underwater operations, notably but not exclusively for perception and decision-making. In 2023, the focus included the use of marine robots in the energy sector, bringing researchers and engineers together to discuss different use cases, specifically for oil and gas, offshore windfarms and nuclear plants. Perhaps reflecting the growth in interest in marine robotics, the number of participants in this topic group has doubled over three years to around 120 members.

While the **Harsh Environments** topic group places a key focus on the use of robots in nuclear facilities, its field of interest extends to marine and other settings which are highly hazardous for human activity. Depending on the specific activity, the marine environment is often too dangerous or technically challenging for human divers and standard industrial robots, making specialized automation crucial for sustainable maritime activities. As the dedicated community for robotics in harsh environments, this group deals with robotics for environments that are so extremely harsh that they require the use of specialised robots not only because humans cannot work in these conditions, but because standard robots cannot withstand the impact of these environments. Such robots need to have specific design features of mechanical construction, mechatronics, navigation, communication and control systems, in order to work effectively in the given environment. Harsh environments continue to pose design challenges for the effective deployment of robots. As with other topic groups this group acts as a common platform for sharing of information and bringing together European experts into a network to address remaining gaps in knowledge and application.

Inspection & Maintenance (I&M) robotics encompasses a large variety of different robotic systems and autonomous vehicles including for use in marine environments both at surface level and underwater. These domains include, but are not limited to, water and waste, oil and gas, transportation, energy generation and distribution, processing industry, aquaculture, maritime, and buildings and infrastructure. In particular, robots have become crucial for inspecting infrastructure such as pipelines, wind farms, and aquaculture systems,

Robotics for I&M in these domains are starting to become a common feature in marine environments, with discernible benefits in risk reduction for human health and safety and environmental protection, and cost reduction.

The **Space** topic group promotes the application of space robotics technologies—such as autonomous navigation and robotic arms—to deep-sea exploration, subsea maintenance, and offshore energy infrastructure (oil and gas, and wind energy) operations.

As an association, euRobotics draws its members from both academic and industrial organisations. Its annual awards competition recognises outstanding contributions across the knowledge arc from creation to application, from PhD level research through technology transfer to entrepreneurship and sustainability. The association connects researchers and industry stakeholders to facilitate the transfer of robotics technology from the laboratory to industry. In this way it supports the development of robotic systems in several maritime sectors, such as offshore renewable energy, aquaculture, and underwater infrastructure maintenance. With its focus on sustainability, the association highlights the use of AI and robots for environmental monitoring, marine pollution cleanup, and broader ocean management.

One of euRobotics' primary aims is to strengthen the competitiveness of European companies, facilitating the transition towards a resilient and sustainable blue economy by fostering cooperation in underwater robotics and marine AI.

Through its strategic roadmapping activity, euRobotics creates roadmaps to guide research and investment in sustainable technology. In A Unified Vision for European Robotics (December 2024), euRobotics emphasised the importance of a 'triangle of research, industry and policy makers (at both national and European levels) all working together within a common framework to support innovation from lab bench to market in an unbroken chain.' As in other domains, achieving sustainable growth in the ocean space calls for a multi-level collaboration in which industrial, environmental and national interests can be balanced.

The association supports broader European efforts to achieve sustainability, including the Sustainable Blue Economy Partnership (SBEP), which brings together nations to invest in ocean health and research.

This paper was produced by euRobotics aisbl (editor: Steve Doswell), in collaboration with NORCE and SINTEF. Please address all comments and queries to: communication@eu-robotics.net