Photo: ScoutDI

Report

Market Study on Inspection and Maintenance Robotics in Norway

Suppliers, Market Needs and Challenges

Author(s):

Mariann Merz, Aksel A. Transeth, Linn Danielsen Evjemo, Eleni Kelasidi

Report No:

2023:00938 - Unrestricted

Client(s) (pos partner):

The Research Council of Norway (RINVE project); the European Commission (RIMA project)

SINTEF Digital
Postal address:
Postboks 4760 Torgarden
7465 Trondheim, Norway

Switchboard: +47 40005100

info@sintef.no

Enterprise /VAT No:
NO 919 303 808 MVA

Report

Market Study on Inspection and Maintenance Robotics in Norway

Suppliers, Market Needs and Challenges

KEYWORDS
Robotics
Automate
Inspection
Maintenance
Market

VERSION
Version 1.0

DATE
2023-09-01

AUTHOR(S)
Mariann Merz, Aksel A. Transeth, Linn Danielsen Evjemo, Eleni Kelasidi

CLIENT(S)
The Research Council of Norway (RINVE project); the European Commission (RIMA project)

CLIENT'S REFERENCE
RINVE (328799), RIMA (824990)

PROJECT NO.
102026178/328799, 102019960/824990

NO. OF PAGES
44

SUMMARY
New and more complex industrial applications of robotic systems for inspection and maintenance (I&M) purposes are enabled by the continuous improvements to the system capabilities. Key factors that fuel this development are advancements in Artificial Intelligence (AI), improvements of sensor technology, miniaturization and cost reduction of components (including motors, batteries, processors and sensors) as well as increased connectivity and high-speed communication technologies. On the other hand, more sectors recognize the potential of automation and use of robots to solve key challenges such as reducing labour costs, minimizing human errors and increasing both the efficiency and availability of the relevant process.

In this report, we review the state-of-the-art in I&M robotics technologies, identify key Norwegian stakeholders and discuss options for the best way forward for increased adoption of this technology in Norway based on the input from some relevant stakeholders.

PREPARED BY
Mariann Merz

SIGNATURE
Mariann Merz
Mariann Merz (Sep 6, 2023 12:55 GMT+2)

CHECKED BY
Marialena Vagia

SIGNATURE
Marialena Vagia
Marialena Vagia (Sep 6, 2023 12:56 GMT+2)

APPROVED BY
Sture Holmstrøm

SIGNATURE
Sture Holmstrøm
Sture Holmstrøm (Sep 6, 2023 13:44 GMT+2)

REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
2023:00938	978-82-14-07854-1	Unrestricted	Unrestricted

COMPANY WITH
MANAGEMENT SYSTEM
CERTIFIED BY DNV
ISO 9001 • ISO 14001
ISO 45001

Document history

VERSION	DATE	VERSION DESCRIPTION
0.5	2023-06-15	First complete version of the report that was subject to internal review and commenting.
0.9	2023-08-17	All internal comments have been addressed and the report is ready for final quality assurance.
1.0	2023-09-01	The report has been updated based on the comments resulting from quality assurance.

SINTEF

Table of contents

APPENDICES

List of Abbreviations

Abbrevation	Definition	Additional description (if needed)
AUV	Autonomous Underwater Vehicle	
CUI	Corrosion Under Isolation	
DIH	Digital Innovation Hub	More information: https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs
I&M	Inspection and Maintenance	
HSE	Health, Safety and Environment	
O&G	Oil and Gas	
RAAS	Robotics-As-A-Service	
RIMA	Robotics for Inspection and MAintenance	https://rimanetwork.eu/
R&D	Research and Development	
ROV	Remotely Operated Vehicle	
SME	Small and Medium-sized Enterprise	
TRL	Test Readiness Level	
UAS	Unmanned Aerial System	
USV	Unmanned Surface Vehicle	
UUV	Unmanned Underwater Vehicle	
VTOL	Vertical Take-Off and Landing	

1 Introduction

Regular inspections and maintenance of infrastructure or equipment are critical to the safe and efficient operation in both the industry and public sector. Inspection and maintenance (I&M) robotics is a field that is experiencing rapid growth. The inspection robots market size was valued at USD 940 million in 2020 and is projected to increase with over USD 13,000 million by 2030[1]. Use of robotics for maintenance applications requires higher precision and more complex manoeuvres and hence lags behind inspection applications, but this market is expected to pick up as the technology becomes more mature.

Key motivations for using robotic systems for I&M tasks include to remove or reduce exposure of personnel to dangerous areas (avoid human entry, remote inspections, etc.), improve quality (improve consistency, repeatability, documentation, better coverage, beyond-human-capability sensing, no fatigue, etc.) and efficiency (automated data gathering, quick retrieval of on-location data, access to difficult-to-reach areas, etc.) of I&M operations, and reduce investment and operations costs.

1.1 Background

This market study is initiated based on SINTEF's involvement in the EU Horizon Europe project RIMA and the national RINVE[2] network, as well as SINTEF's participation in SPRINT Robotics[3] and coordination of the euRobotics[4] topic group on I&M robotics. Robotics for Inspection and Maintenance (RIMA) is a 4-year project aiming to establish a network of 13 Digital Innovation Hubs (DIHs) and industry associations across Europe to support the uptake of robotics in different industry sectors. RINVE is a Norwegian network co-financed by the Research Council of Norway and will contribute to the development in the Norwegian

[1] https://www.alliedmarketresearch.com/inspection-robots-market-A08254
[2] https://www.sintef.no/projectweb/rinve/
[3] https://sprintrobotics.org/
[4] https://eu-robotics.net/

business community of automation and robotization within inspection and maintenance. An important aspect of this is RINVE's goal of helping to mobilize for increased Norwegian participation in EU projects within inspection and maintenance robotics.

1.2 Purpose

The purpose of this report is to provide insight into the Norwegian I&M Robotics market, who the main technology- and service-providers are, what end users that are currently applying such solutions, and what the key obstacles that hinder a more widespread use of the technologies are. Additional objectives include to identify what types of new technologies that will have to be developed/matured given the end user needs, what the near-term R&D challenges are (1-3 year out) and to determine the key challenges that technology developers currently face when trying to bring a new robotic solution to the market. The main goal of collecting this information is to help to identify and alleviate obstacles that hinders the uptake of I&M technologies in Norwegian industries.

1.3 Scope of the Report

The report is limited to robotics that may be relevant for I&M applications and to companies that have one or several physical locations in Norway. The list of technology and service providers and end users included in this report can by no means be considered complete or up to date by the time of publishing (as this is a dynamic market), but it is a product of the time available to perform the survey and the ease of obtaining information about each entity.

1.4 Acknowledgements

The authors would like to thank all the companies that took the time to respond to our survey or otherwise provided input for this report.

2 Description of Methods used for the Study

This work aims to contribute to increased uptake of robotics technology for I&M applications; hence it focuses on mapping the key stakeholders and identifying the key challenges that they face. Successful technology providers typically succeed in being among the first to cover some gap that exists between the current state-of-the-art technology and (at least one aspect of) an attractive solution to end user challenges. To solve very complex problems, several different types of innovations may be required to provide a viable solution. Thus, a good understanding of both a wide selection of current state-of-the-art technology solutions as well as the detailed I&M challenges that end users face are critical for all entities that are interested in helping to drive the I&M robotics technology adaptation forward (e.g., technology and service providers, research institutions). As illustrated in Figure 1, there are other types of potential obstacles to new technology development than the purely technological ones (such as regulatory and financial obstacles), that are equally important to address to achieve a viable solution and commercial success. It is also evident that such a development process is extremely demanding for the technology providers and that some may run out of room to act before they secure their first sales.

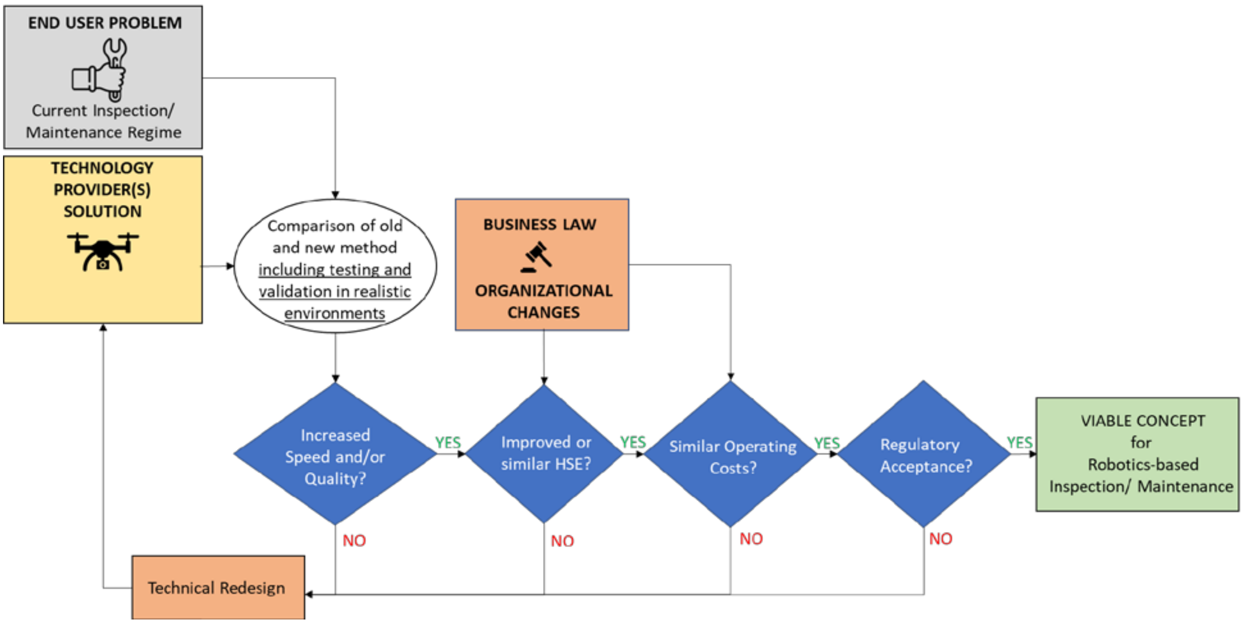

Figure 1: Illustration of factors that influences the robotics-based inspection/maintenance solution.

Accordingly, the approach taken in this study involves a 3-pronged approach, that 1) examines the State-Of-The-Art of relevant technologies for inspection and maintenance robotics (including relevant recent market surveys), 2) compiles a list of relevant Norway-based I&M robotics technology and service providers, service providers and end users, and 3) collects input from key Norway-based I&M robotics technology providers, service providers and end users and try to identify their key challenges. The input from key stakeholders was collected through an online survey that was distributed to the members of the RINVE network.

2.1 Identification of Relevant Applications for I&M Robotics

Within each industry, it can be challenging to identify the tasks and processes where the introduction of robotics has a high potential to be successful. Based on previous experience we know that the following criteria serve as key indicators that a task may be suited for robotization:

1. **The current process/task should be clearly defined.** It should be possible to describe it either in terms of a recipe or a set of rules.

2. **The current process/task should have significant potential to cut cost** (either financial or health-/safety-related). This will typically mean that the task must be frequently performed (high volume), require dedicated personnel, involve a lengthy preparation time (scaffolding, removal of insulation or similar) and/or production downtime, involve high risk of costly human-errors, involve risk of person injury or death, or involve high impact to other HSE factors.

Additionally, the following might provide an extra incentive for robotization (although most of this is implicitly covered by point 2 above):

3. The current process/task has an **element of urgency**, where e.g., fast "on-demand" action will help to minimize the consequences of a failure.
4. The current process/task involves high potential gains if more **frequent and repeatable inspections** are performed, i.e., the increased maintenance intervals etc.
5. The current process/task is very **repetitive** and/or involves **work that employees dislike** (such as monitoring equipment during the weekend)
6. The current process/task requires a very **high degree of quality and precision** which is difficult for humans to maintain for long periods at a time. Similarly, the use of robotics can increase the quality of a product, making it more attractive to buy and hence, increasing the market share.
7. The process/task of interest takes place in a location with **limited personnel** and a high inspection and maintenance workload, e.g., an offshore installation.
8. The current process/task requires **production shutdown or infrastructure closure** (e.g., road/rail/runway closure) that may be avoided with use of a robotics-based solution.
9. The existence of a promising market potential for the robotic solution outside the direct application in the targeted industry (i.e., within industries that may not be able to directly fund the technology development).

2.2 End User Information Gathering

Relevant input collected from end users has the potential to provide valuable insights to the study. To accomplish this, a two-step approach was selected for this report:

1) A small 1-page description of the study along with a short list of key questions was composed and distributed to a small group of test participants and revised based on the feedback provided.
2) End users connected to the RINVE network were contacted via email providing the revised 1-page summary along with a link to a Microsoft Forms survey for simple completion of the survey.

The online format of the survey was chosen to make the threshold for participating sufficiently low. The questions that were included in the survey are included in Appendix A.1.

2.3 Technology and Service Provider Information Gathering

Input from Norwegian technology and service providers can help to identify what type of support is needed to ease their path toward commercial success. Once the providers have arrived at a viable product concept and have developed the first prototype, they still face major challenges. The full development chain from idea to commercial product is illustrated through the Technology Readiness Levels (TRLs) summarized in Figure 2.

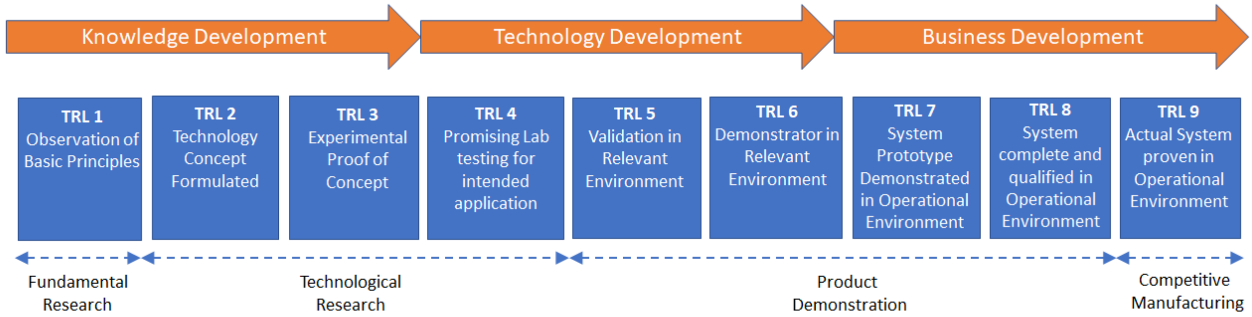

Figure 2: The Innovation Chain – The Development from Idea to Commercial Product

A similar survey approach as for the End Users was selected but this time focusing on identifying the main hurdles of the providers. The detailed survey questions that were distributed to the technology and service providers are shown in Appendix A.2.

3 Current I&M Robotics Market and key Commercial Stakeholders in Norway

3.1 Overview of relevant market studies

Table 1 provides a brief summary of recent, relevant market studies.

Market Study Name (Authorship)	Date published	Brief description (Based on the "Open access" information available for the publication)
Service Robotics Market by Environment, Type (Professional, Personal & Domestic), Component, Application (Logistics, Inspection & Maintenance, Public Relations, Education, Personal), and Geography 2026 (MarketsandMarkets)	August 2021	The service robotics market size is projected to reach $103.3 billion by 2026. The highest growth is expected in the market for aerial drones, pointing at applications such as surveying farm fields and traffic monitoring. Also the market for software components is expected to grow more than the market for hardware components. The report can be purchased from: https://www.marketsandmarkets.com/Market-Reports/service-robotics-market-681.html
Inspection and Maintenance Robot Market 2022 Global Analysis, Technology Update and Segmentation, Applications and Forecast Study by 2028 (SNS Insider)	May 2022	The Inspection and Maintenance Robot Market Size was valued at US$ 2.4 billion in 2021 and is anticipated to reach US$ 6.31 billion by 2028. I&M robot market size, share & segments by type (autonomous, remotely operated), by application (oil & gas, food & beverage, utility, others), by type (loader, cranes, forklift, excavator, dozers, others), by component (Hardware, Software), and by regions. The report can be purchased from: https://www.snsinsider.com/reports/inspection-and-maintenance-robot-market-1364
Global Inspection Robots Market Outlook - 2030 (Allied Market Research)	August 2021	States that the inspection robot market size was valued at $940.9 million in 2020 and is expected to reach $13,942.5 million by 2030. Inspection robots market by robot type (stationary robotic arm and mobile robots), testing type (automated metrology and non-destructive inspection) and end-user (Oil&Gas, Food&Beverages, Pharmaceuticals, Electronics and Others). The report can be purchased from: https://www.alliedmarketresearch.com/inspection-robots-market-A08254
Market Analysis of Robot and Automation Firms in Norway (HowToRobot, Gain&Co, NFEA)	12 October 2022	Provides an Overview of 131 robot and automation suppliers in Norway. The report can be purchased from: https://howtorobot.com/
Global Inspection and Maintenance Robot Market:	March 2020	Predicts that I&M Robotics market will grow at a compound annual growth rate (CAGR) of 12.73%

Focus on Type, Component, and End User - Analysis and Forecast, 2020-2025 (BIS Research)		on the basis of value during the forecast period from 2020 to 2025. Furthermore, it is noted that Europe dominated the global I&M robot market with a share of 40% by value in 2019. The report can be purchased from: https://www.bccresearch.com/partners/bis-market-research/global-inspection-maintenance-robot-market.html
Robotics for inspection & maintenance Market study - phase 3/3 (RIMA project)	Nov 2022	Overview of market aspects for I&M robotcs in rail, electrical grids, nuclear, O&G, aviation (planes), water and wind turbine farms.
State of the Nation – Norges tilstand 2021 (Rådgivende Ingeniørers Forening, in Norwegian)	2021	Condition assessment and need for maintenance for key infrastructure in Norway including, e.g., hospitals, rail, aviation, roads, water, etc. https://rif.no/state-of-the-nation/

Table 1: A summary of recent and relevant market studies

3.2 Brief Summary of the State-of-the-art I&M Robotics Technologies

It is obvious that not one single robot system can cover all types of end user tasks and applications. To develop clear and realistic ideas of future opportunities and developments involving robotics, it is critical to have a good understanding of the current status of I&M Robotics technologies. It is not possible to cover this broad topic in much detail within this report, but a brief overview is included to make the rest of the report accessible to more categories of readers. The summary of state-of-the-art is partly based on SINTEF's expert insights and knowledge in this field which is supplemented by a brief literature review of recent developments.

Inspection is a key element of any structural maintenance program. Once degradation is detected, the plans for repair or replacement, as well as choosing between the two, can be initiated. Furthermore, inspection methods have been developed to detect early signs of fatigue or failure even prior to signs of deterioration are visible. Advanced health monitoring systems have the additional benefit of allowing the maintenance activities to be planned and scheduled in a more effective manner, and the monitoring can for instance include thermal, fluid consumption (e.g., use of lubricants) and vibration properties. A recent trend to realize safety and cost benefits has been to replace the human-oriented inspection procedures with various smart camera-platforms. Robots can serve as mobile sensing platforms if the inspection or surveying problem at hand requires mobility. Different types of robotic inspection systems in use today include fixed-base robots, rail mounted robots, wheeled robots, snake robots, climbing robots, floating robots, underwater robots and aerial robots as illustrated in Figure 3. Bipedal/humanoid robots are still placed firmly in the research world and are thus not included.

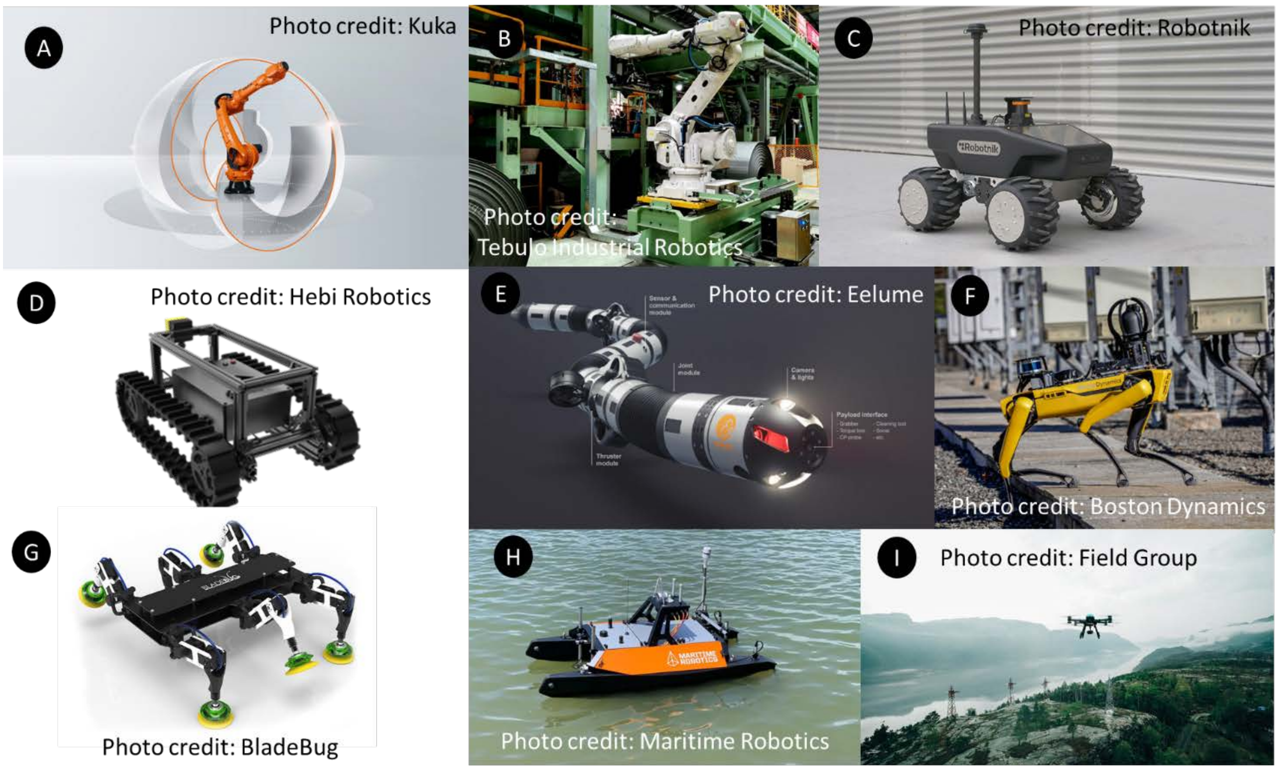

Figure 3: Different types of Robotic Platforms. A) Fixed-base robotic arm by Kuka, B) Rail-mounted robotic arm by Tebulo Industrial Robotics, C) Wheeled Summit-XL robot by Robotnik, D) R-series tracked mobile base by Hebi Robotics, E) Underwater Snake Robot by Eelume, F) Spot 4-legged robot by Boston Dynamics, G) Crawling/climbing robot by BladeBug, H) Unmanned Surface Vehicle Otter by Maritime Robotics, I) Unmanned Aerial System by Field Group.

Note that some of the robotic platforms have been adopted for applications beyond pure inspection/surveying. In the following sections we will briefly discuss relevant applications as well as key limitations that the systems face. We will organize the systems into the following six categories: 1) Robotic arms with physically restricted reach, 2) Wheeled or tracked ground robots, 3) Legged robots, 4) Snake robots, 5) Underwater and Surface robots, 6) Aerial robots.

Furthermore, most robots can be tailored to the specific application at hand, i.e., the best solution will depend on the detailed use case. Particularly relevant aspects to consider include:

- A tether that can provide "unlimited" power from another facility/vessel/vehicle/robot at the cost of reduced mobility.
- Compatibility with a charging/docking station to enable long duration autonomy at the cost of added system cost and complexity.
- Full autonomous operation, including robust collision and avoidance and dynamic path planning at the cost of added system cost and complexity.

3.2.1 Robotic arms with physically restricted reach (fixed-base, rail-mounted base)

The first industrial robot was the Unimate robotic arm that was installed on a General Motors assembly line in 1961 and that subsequently evolved into the PUMA arm[5]. Since that time, the development of industrial robotic arms has continuously moved toward more dexterous devices, with an increasing

[5] https://en.wikipedia.org/wiki/Programmable_Universal_Machine_for_Assembly

number of degrees-of-freedom, and capabilities surpassing the human arm [1]. The automotive industry is still leading the way as the industry with the largest implementation of robots into the production, accounting for 33% of total supply of robots in 2019 [2]. A more recent status of the industries that are currently busy adopting robotics technology are summarized in Figure 4.

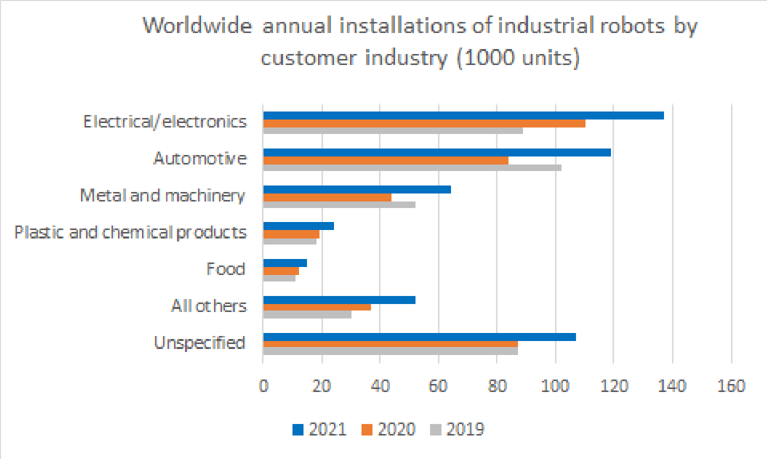

Figure 4: Number of Industrial Robots per Industry Type (reproduced from the 2022 World Robotics report by IFR[6])

Since the automotive industry typically uses assembly line production many of the robots used are fixed-base or rail-mounted robotic arms of varying sizes, capacities and abilities. The work performed includes welding, painting, sealing, assembly, tending milling machines, placing, picking, cutting/trimming and internal logistics such as moving parts around as shown in Figure 5.

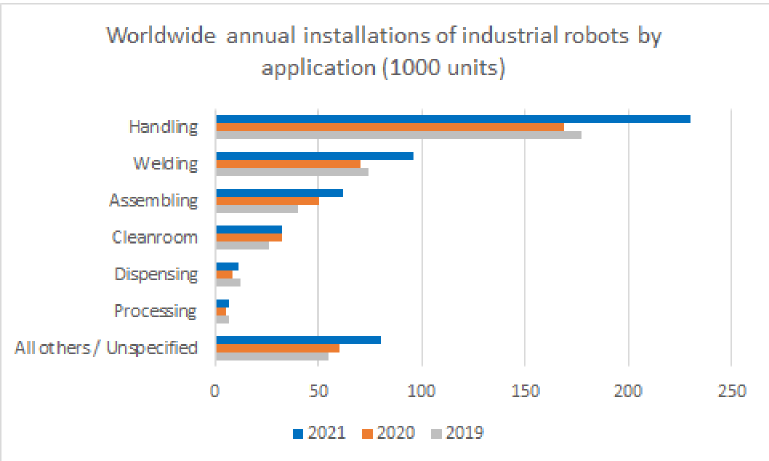

Figure 5: Industrial robots per Application (reproduced from the 2022 World Robotics report by IFR[3])

Current areas of research in this sector include enhanced robot vision as well as collaborative robots that are instrumented with sensors and control algorithms to safely and effectively work beside each other or a human worker. The main limitation of advanced robotic arms is the limited work envelope which does not offer the needed flexibility for all applications. The more advanced systems can move autonomously from location to location, detecting and avoiding obstacles in their path along the way.

[6] https://ifr.org/worldrobotics

3.2.2 Wheeled or Tracked Robots

Wheeled or tracked robots, where the locomotion stems from artificial rotational devices, come in many different shapes and sizes and are optimized by the tasks they are intended for. Beyond use as a mobile inspection platform, typical applications include transportation of goods inside a factory, facility or out to an end consumer and to vacuum/clean or disinfect surfaces. A recent trend involves mounting robotic arms on top of a wheeled/tracked ground robot to be able to perform a wider range of missions. Examples of commercially available robot platforms in this category includes Robotnik XL-GEN[7] and Taurob Inspector[8] that are shown in Figure 6.

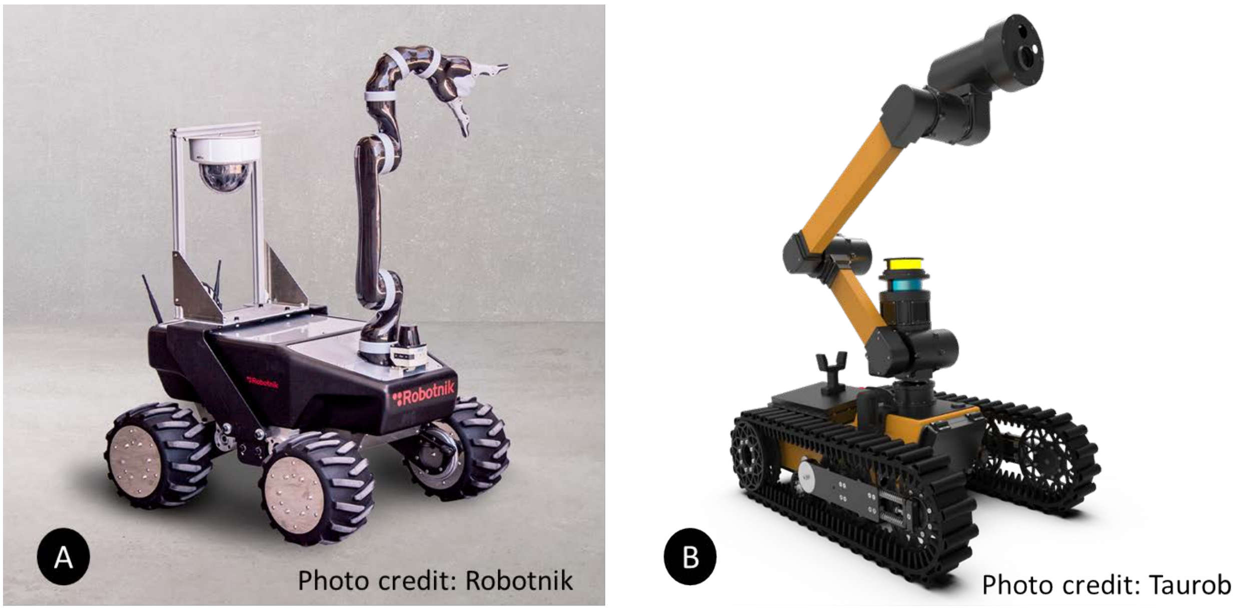

Figure 6: Wheeled/tracked I&M Ground Robots A) XL-GEN from Robotnik, B) Taurob Inspector from Taurob.

An important subcategory of wheeled robots are crawlers intended for I&M of pipes or other confined spaces. A wide selection of commercially available solutions is available from companies such as Waygate Technologies[9], Fiberscope[10] and Eddyfi Technologies[11]. Stormer S3000 from Fiberscope and LineTrax mini-crawler from Eddyfi technologies is shown in Figure 7.

[7] https://robotnik.eu/products/mobile-manipulators/xl-gen/
[8] https://taurob.com/taurob-inspector/
[9] https://inspection-robotics.com/mobile-robotics-2/
[10] https://www.fiberscope.net/pipe-inspection-robot/
[11] https://store.eddyfi.com/products/systems/crawlers-and-automation.html

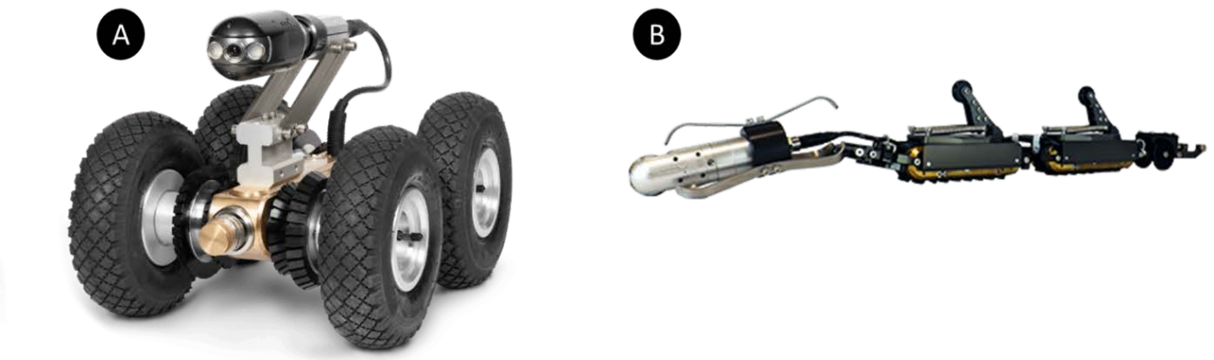

Photo credit: Fiberscope   Photo credit: Eddyfi Technologies

Figure 7: Pipe Inspection Crawler Robots A) Stormer S3000 from Fiberscope, B) LineTrax mini crawler from Eddyfi Technologies.

It should also be noted that some very specialized platforms that are designed for a specific application are operating within this category. Examples are the line-suspended *LineScout* platform developed by Hydro-Québec that is designed for I&M of energized transmission lines [3] and the *CableScan* robotic crawler for inspection of cable-stayed bridges[12] that are shown in Figure 8.

Figure 8: I&M Robots for Specific Applications. A) LineScout platform developed by Hydro-Québec that is designed for I&M of energized transmission lines, B) CableScan robotic crawler for inspection of cable-stayed bridges.

3.2.3 Legged Robots

A legged robot is extremely well suited to move around in infrastructure/facilities that are built for human operators. Tasks such as climbing stars and crossing doorsteps may be a challenge for other mobile robot platforms. Furthermore, a legged robot may be better suited to traverse very cluttered terrain such as a boulder field or a collapsed building. However, the increased mobility comes at the cost of higher complexity and power consumption compared to wheeled/tracked robots. Currently, robot platforms with 4 legs are available commercially, including Spot developed by Boston Dynamics[13] and ANYmal developed

[12] https://infraspect.com/cablescan/
[13] https://www.bostondynamics.com/products/spot

by ANYbotics[14]. A brief summary of the main characteristics and limitations of the two systems (per the specification on the companies' respective webpages and datasheets) are provided in Table 2. This information has been included here to provide an idea of the state-of-the-art performance of this emerging technology.

Main characteristics	Spot by Boston Dynamics	ANYmal by ANYbotics (Generation D)
Autonomy	Teleoperated or fully autonomous with obstacle avoidance.	Teleoperated or fully autonomous with obstacle avoidance.
Max step height  Image Credit: Anybotics	Maximum 30 cm	Maximum 25 cm
Stairs  Image Credit: Anybotics	Spot does best with staircases that meet U.S. building code standards, typically 18 cm (7 in) rise for 25 to 28 cm (10 to 11 in) run.	Maximum 45 deg, max rise 23cm, min run 21 cm, min width 80 cm. Handles open risers and grated steps.
Slope  Image Credit: Anybotics	± 30 deg incline	± 30 deg incline
Gap  Image credit: Anybotics		Maximum 30 cm gap
Crawl  Image credit: Anybotics	Minimum walking height is stated to be 52 cm	Minimum 60 cm gap
Payload	Maximum 14 kg of inspection equipment. Also an option of 6 DOF arm with gripper.	10 kg under nominal conditions, but up to 15 kg at reduced operating speed or operating time.
Battery duration	90 minutes battery run time	90 minutes battery run time
Battery charging	Automatic connection to docking station. 80% charge after 50 minutes. 100% charged after 2 hours.	Automatic connection to docking station. 70% charge after 100 minutes. 100% charged after 3 hours.
Cost estimate	$75,000[15] - $205,000[16]	$150,000[17]
Ruggedness	IP54	IP67, ANYmal X is an Explosion-proof version (ATEX Zone 1)
Customers	Aker BP, NASA JPL, Woodside, Pomerleau, National Grid, +more	Petronas. Early adopters program for ANYmal X: Equinor, Petrobras, Woodside, Shell

[14] https://www.anybotics.com/anymal-autonomous-legged-robot/
[15] https://arstechnica.com/gadgets/2021/02/boston-dynamics-robot-dog-gets-an-arm-attachment-self-charging-capabilities/
[16] https://thestack.technology/how-much-does-boston-dynamics-spot-cost-uk/
[17] https://www.cnbc.com/2021/12/26/robotic-dogs-taking-on-jobs-in-security-inspection-and-public-safety-.html

Table 2: Performance summary of 4-legged inspection robots

No known bipedal robot platforms suited for I&M missions are yet commercially available.

3.2.4 Snake Robots

A snake robot is typically designed to reproduce the motion of biological snakes and are made up by multiple actuated joint/modules. A key benefit that all snake robots share is the slender shape that allows them to enter and traverse tight spaces and constrained environments. The system is typically hyper-redundant, allowing several joints to fail while still being able to maneuver. Their flexibility in altering the shape of their bodies also allows these robots to traverse obstacles such as stairs and cluttered terrain, while still being able to move through narrow passages. Relevant applications include surgical applications [3], search and rescue [4], and inspection, maintenance and repair, e.g., of subsea installations (currently being commercialized by Eelume[18]), sewers, etc.

3.2.5 Underwater and Surface Robots

There are many different types of robots that are developed for applications where the robot is fully or partially submerged. Harsh operating environments coupled with a potential lack of human presence leads to hard-to-achieve requirements for robustness and reliability of the systems. However, for the same reasons, autonomous robots are a very good alternative to manned missions into these environments.

Today, unmanned underwater vehicles (UUVs) are used in a wide range of applications, from archeology and resource exploration to marine biology and oceanographic research. Equipped with cameras, sonars and other sensors, underwater robots can perform a variety of inspection tasks in areas it would otherwise be difficult to reach. This can be inspection tasks close to the surface, such as inspection of biofouling or corrosion on ship hulls, dam inspections or inspections of constructions or moorings in harbor areas [5]. However, it can also be inspection tasks performed on greater depths, such as in the oil and gas industry, where underwater robots are used to perform rig site surveys, acoustic inspections of pipelines and other underwater installations, construction site surveys etc. UUVs can be used to find objects on the sea floor in both search and rescue and archeology. In science, UUVs can perform tasks such as geological surveys, geophysical surveys, seabed mapping, coastal mapping, and marine biology studies.

There are several different types of underwater robots used in both inspection and maintenance. The choice of underwater robot depends on the technical demands for the specific application, and the conditions of the underwater environment. Remotely operated vehicles (ROVs) are tethered underwater vehicles, often operated by a human pilot from the surface. Power is delivered through the tether, allowing ROVs to operate for prolonged periods of time without being restrained by battery time. Larger amounts of data can also be transmitted to the surface in real time because of the tether, though the length of the tether naturally limits how far away from the surface vehicle an ROV can travel. Other autonomous underwater vehicles (AUVs) can be tetherless and are programmed to autonomously perform a pre-defined task. Robots that travel along the ocean floor or other underwater surfaces are called crawlers. Maritime robot crawlers can be specifically designed for cleaning ship hulls, such as the Jotun Hull Skating solution (Norway)[19]. Moreover, Oceantech (Norway) has developed and tested a robot for inspecting infrastructure in the splash zone (i.e., where there are waves) and for underwater infrastructure[20]. Operations using underwater robots can often be combined with surface robots, such as remotely operated unmanned surface vehicles (USVs) or autonomous surface vehicles (ASVs). Surface

[18] https://eelume.com/
[19] https://www.jotun.com/ww-en/industries/solutions-and-brands/hull-skating-solutions/overview
[20] https://oceantech.no/inspection/

robots are also equipped with a series of sensors, and are used in operations such as oceanographic research, marine surveillance, or for search and rescue in conditions that are too dangerous for human operators. Examples of commercially available robot platforms in this category includes the Argus Worker for deepwater missions and the Ocein StealthCleaner for cleaning or fishfarming nets shown in Figure 9.

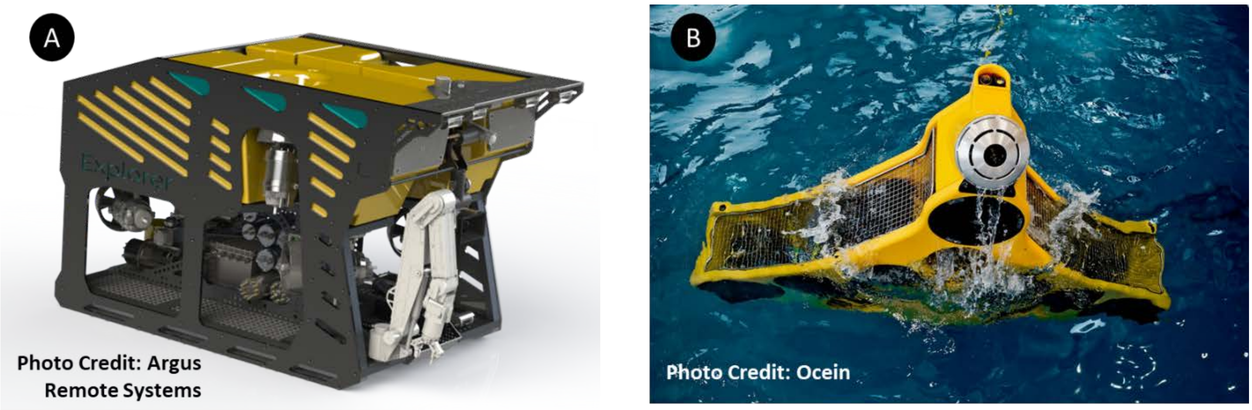

Figure 9: Robots for underwater applications. A) Argus Worker developed by Argus for deepwater operations, B) StealthCleaner from Ocein for cleaning of fishfarming nets.

Using underwater robots to perform tasks in high-risk environments also removes or strongly reduces the need to use divers, which always presents a significant risk to the humans involved. This risk increases with working in deep waters, strong currents, and in dynamically changing environments. One example of this is the aquaculture industry: The operations are done in the splash zone, with strong influences from waves and changing currents compared to underwater operations on deeper waters in for example the oil and gas industry. The fish cages themselves are flexible and moving structures that will have deformations based on the environmental conditions. They are fastened by mooring lines to the seabed, and each cage typically contains approx. 200 000 freely moving fish that should not be harmed or frightened. Robots can contribute through a variety of inspection tasks, such as inspections of both biofouling and potential damage to the net and mooring lines, the behavior of the fish in crowding operations etc. Current technological development also focuses more on intervention tasks, for example net cleaning robots that can remove biofouling in a way that gives less negative impact on the fish, and reduces risks, stress and strain on the human operators.

3.2.6 Aerial Robots

Unmanned Aerial Vehicles (UAVs) or drones are increasingly adopted for various industrial applications. The main obstacle to preventing more widespread implementation this far has been acceptable robustness (particularly related to the communication and control link). The ability to provide the aerial perspective in an effective manner offer great value to most industries and particularly to large sites such as oil and gas facilities [6], air- and seaports[21,22], mining fields [7] and construction areas [8]. A vast number of different aerial robots are available, each aiming at solving a set of end user challenges. *Fixed-wing drones* offer long-range, high speeds and long flight times while *multirotor drones* offer great maneuverability (including the ability to hover in a fixed position) and require minimal ground infrastructure. There are also solutions that bridges these two main categories, such as tether-systems for multirotor drones and Vertical TakeOff and Landing (VTOL) platforms that can take off and land vertically like a multirotor but can fly fast efficiently like a fixed-wing.

[21] https://www.airport-technology.com/analysis/positive-uses-of-drones-in-aviation/
[22] https://safety4sea.com/wp-content/uploads/2020/11/BPA_Aerial_drones_and_ports-2020_11.pdf

Aerial drones are typically developed for outdoor use, but they are increasingly adopted to indoor (e.g., warehouse inventory) or underground operations and researchers are working to solve the associated challenges presented by GPS-denied navigation, confined spaces, cluttered environments and reduced visibility [7, 9].

3.3 An Overview of Norway-based Providers of Technology, Services and Integration

It is often necessary to make adjustments to a particular robotic solution to operate efficiently and in accordance with relevant rules and regulations for the particular use case. Thus, it may be advantageous for an end user to collaborate with a technology provider or service provider located in the same region. We make the following distinction between end user, technology provider, service provider and distributor:

- **End User**: An infrastructure owner and/or operator who is responsible for the general upkeep of the facility.
- **Technology Provider**: A company that produces and sells a piece of technology that is particularly relevant for I&M robotics applications.
- **Technology Integrator**: A company that combines different typically off-the-shelf technologies into a solution to a specific user application. They may also produce some of this technology themselves and effectively be both a technology provider and a technology integrator.
- **Service Provider**: A company that either provides a service of integrating several technologies into a complete I&M robotics solution for a particular use case or that provides a service using their own I&M robotics equipment to generate needed data for the customer.
- **Providers**: Category that includes technology developers, technology integrators and service providers.
- **Distributor**: A company that sells off-the-shelf parts and solutions that are produced by other companies. Pure distributors are not included in the overview.

In this section we will summarize the technology providers, technology integrators and service providers that are most relevant for I&M robotics applications and that have at least one office in Norway. The summary covers all the companies that the authors have been able to identify (based on existing network and information available online) but cannot be considered complete or fully up to date. Due to the special focus on I&M robotics technology, technology providers for general automation applications, including control system and HMI solution providers have not been included. However, robotics companies that are not specifically addressing I&M applications have been included as there may be opportunities to adapt some of these solutions to I&M relevant tasks. Note that the brief descriptions of each company are based on information easily available online (e.g., company website).

3.3.1 Providers relevant for Robotic Manipulators

In this section we also include robotic manipulators mounted on e.g., gantry cranes or tracks, but not on mobile bases with greater range (e.g., wheeled bases, etc.).

Norway-based Providers particularly relevant for ***robotic manipulators***		
Company	**Location**	**Brief description**
ABB AS	Several	Manufacturer of industrial robots, including a wide range of different arms and cobots for nearly all types of industries.
Aivero AS	Stavanger	Creates software for real-time 3D vision for robots with arms. "Aivero See is a 3D machine vision service that simplifies the large-scale use of 3D video cameras".[23]

[23] https://www.aivero.com/machine-vision-as-a-service/

SINTEF

Aluflex System AS	Jessheim	Manufacturer of industrial automation solutions including AluFlex Robot Track System RTS30, a customizable, servodriven and floor mounted Robot track system made for one or two robotplates (max 1200 kg, up to 100 meters with max speed of 2 m/s).
Amatec AS	Sykkylven	Amatec Automasjon provides integration services within automation and robotics, including building and programming complete robot cells.
Applica AS	Kristiansand	Integrator of customized solutions with industrial robots. Special focus on robot vision.
APX Systems AS	Oslo	Develops software (APX Avatar) that can coordinate several robots and help with the production flow or warehouse logistics. Can deliver complete solutions including robots and robot control.
Artec Automation AS	Fjellhamar	Integrator that customizes automation and robotics solutions (primarily use of industrial robots from FANUC and mobile robots from MIR) for a wide range of industries.
AURO AS	Solbergelva	Designs, produces and sells customer-specific and standardized industrial robot solutions (mostly Universal Robots and Mitsubishi).
Bergsli Metallmaskiner AS	Skien	Integrator of automation and robotics solutions, including robots from ABB, Omron, EasyRobotics and grippers from Onrobot Gripper.
Blue Robot AS	Tønsberg	Manufactures an Automated Storage and Retrieval System (ASRS) consisting of a gantry moving robot that operates in synchronization with high performance conveyors.
Bouvet	Several locations	Delivers services in robot system integration and software development and integration.
Butler Solutions AS	Jørpeland	Integrator of automation and robotics solutions, including industrial robot arms (EVA cobot, Kinova).
Canpro AS	Nesttun	Integrator of automation and robotics solutions, including Kuka robots and automation systems.
Canrig Robotics	Sandnes	Manufactures modular automated tubular and tool handling systems aimed at drilling rigs (onshore and offshore) including drill floor robot, robotic roughneck, robotics pipe deck handler, robotics pipe handler and robotics pipe feeder.
Cobitek AS	Vikersund	Integrator of automation and robotics solutions, including Universal Robots, ABB, Staübli og Adept.
Cobot-Norge AS	Melhus	Integrator of industrial robots, including solutions based on Dosan cobots, Omron robots and Universal Robots. Delivers standardized cobot applications aimed at end-of-line packaging of food products.
Data Respons Solutions AS	Høvik, Skedsmokorset	Designs, develops and delivers smart embedded and industrial IoT solutions collaborating with leading technology partners. Previous work includes control systems for industrial robots.
Dmg Mori Norway AS	Vestskogen	DMG Mori manufactures metal cutting machines, CNC-controlled Turning centres and Milling machines. Integrates and customizes solutions using industrial robot arms.

Dynatec AS	Askim	Design and manufacture of series and stand-alone machines, that integrates robotic arms as needed with a special focus on robot vision and (food) product handling.
Einar Øgrey Farsund AS	Farsund	Integrator of industrial robots for production lines
Eiva Safex	Several	Integrator that specializes in cranes, vacuum lifters and crane manipulators
Epson Europe B.v. Norway Branch	Høvik	Epson is a manufacturer of robotic arms including the SCARA line and 6-axis robots.
Festo AS	Oslo	Manufactures industrial robots including pneumatic pick and place robots, cartesian robots and delta robots (dynamic response in 3D)
GJ Machine	Skodje	Integrator of automation-relevant technologies, including fully automated production lines for the process industry, robot technology (mostly ABB), tailormade conveyors, and management systems.
Goodtech AS	Several	Integrator of industrial robots and can deliver complete robotized assembly lines.
HF Danyko AS	Grimstad	Advisor and integrator of industrial robots
Honeywell AS	Asker, Drammen	Certified Robot Integrator mainly aimed at logistics and warehouse applications
Imperietek AS	Jørpeland	Integration and programming of industrial robots including Universal Robots, Omron, Siemens, Wago, Unitronix, Beijer, Mitsubishi, ABB.
Intek Engineering AS	Raufoss, Hamar	Develops and manufactures and integrates robots, software and automation for a variety of industries.
ITO Pallpack AS	Oslo	Integrator of industrial robots from Kuka and Universal Robots
Kamelon Gruppen AS	Åros	Certified System Integrator for Universal Robots. The company is a recent merger of Kamelon Solutions AS and Cobotnor AS.
Kemppi Norge AS	Tønsberg	Integrator or industrial welding robot equipment
Knapp AS	Sandvika	Integration of industrial robot solutions for various processes in production and the warehouse: robots for bin picking and robots for fully automatic full-case picking.
Kongsberg TeroTech	Kongsberg	Integrator of industrial robots
Kongshavn Automasjon AS	Godvik	Designs and produces advanced hydraulics and mechanical steel-constructions such as cranes and cargo handling equipment (e.g., vacuum clamps, lifting frames, grabs) for the maritime and oil&gas industries.
Kuka Nordic Norway	Hov	Robot arm manufacturer aiming at a broad range of applications and sectors.
Migatronic Norge AS	Bryne	Integrator and distributor of welding robots.
Omron Electronics Norway AS	Several locations in Norway	Manufacturer of industrial robots, including a wide range of different arms and cobots for nearly all types of industries.
Pioneer Robotics AS	Kristiansand	Integrator of industrial robots that can deliver turnkey solutions from feasibility study to commissioned system.

Prevas AS	Oslo	Integrator of industrial robots, including control systems for robotic cells.
ProduksjonsTeknologi AS	Asker	Integrator of industrial robots, particularly from Universal Robots.
Prodtex AS	Ulsteinvik	"Prodtex can deliver customized automated solutions for different applications. This can be turn-key integrated robot cells, as well as stand-alone robot manipulators."[24]
RoboTek AS	Brattvåg	Integrator of cobots and industrial robots, including Universal Robots and Kuka.
RobotNorge AS	Klepp Stasjon	Integration of cobots and industrial robots (from ABB).
Rocketfarm AS	Sogndal	Specializes in integration of Universal Robot palletizing solutions
Solwr	Ålesund, Oslo, Trondheim.	Develops and integrates the warehouse robots Sort (sorts e.g. pallets) and Grab (autonomous pick and place). The company is a merger of Driw and Concurrence Robotics. "Today, 1/3 of all groceries in Norway go through our systems."[25]
Spesmek AS	Nordkjosbotn	Integrator of industrial robots (including Universal Robots and cobots) and also special design of rebuild of (automated) machinery.
Surface Dynamics	Kristiansand	Develops and manufactures robots for surface cleaning, painting, inspection and data collection and offers these as a service. Includes rail mounted systems and ATEX conformity.
Swisslog AS	Oslo	Integrators of industrial automation and robotics mainly focusing on warehouse logistics. Part of the Kuka Group
Tratec Norcon AS	Vennesla, Farsund, Tiller	Integration and customization of solutions involving industrial robots. Collaboration with Future Robotics and UIA. Partner agreement with Robot Norge.
Tronrud Engineering AS	Hønefoss	Develop and manufacture innovative machines and solutions, including integration of industrial robot systems as required (KUKA, ABB, Universal Robots, Omron AIV and MOTOMAN.
Welmax AS	Larvik	Designs, builds and customizes solutions for welding, combining off-the-shelf machinery and industrial robots (mostly Kuka and ABB) with in-house made software.
Wictus AS	Several	Integrates industrial robots, including complete robot cells using mainly robots from Hyundai, Hanwha and Fanuc.
Zivid AS	Oslo, Trondheim	Develops and manufactures industrial 3D cameras that can be mounted on a robot

[24] https://www.prodtex.no/robot-solutions
[25] https://www.solwr.com/company/about-us

3.3.2 Providers relevant for Wheeled and Tracked Robots

Norway-based providers particularly relevant for ***Wheeled or Tracked Robots***		
Company	**Location**	**Brief description**
ABB AS	Several locations in Norway	Manufacturer of industrial robots, including an autonomous mobile robot family (ABB acquired ASTI Mobile Robotics in 2021). "The first models to be released, Flexley Tug and Flexley Mover, cover applications including towing, trolley transportation up-to 2000kg, as well as lifting and transporting racks, containers, and pallets of 1,500kg"[26]
Adigo Mekatronikk	Langhus	Manufactures concept and prototypes of mobile robots mainly targeting forestry and agriculture applications.
Amatec AS	Sykkylven	Integration of autonomous mobile robots from Omron for different types of applications.
APX Systems AS	Oslo	Develops software (APX Avatar) that can coordinate several robots and help with the production flow or warehouse logistics. Can deliver complete solutions including mobile robots and robot control.
Artec Automation AS	Fjellhamar	Integrator that customizes automation and robotics solutions (primarily use of industrial robots from FANUC and mobile robots from MIR) for a wide range of industries.
Autoagri AS	Vanvikan	Develops an autonomous implement carrier (light-weight tractor) for agricultural applications. Under development, but the company now accepts a limited number of orders.
AutoStore	Nedre Vats, Oslo	A warehouse robot technology company that invented and continues to pioneer cube storage automation.
Axess AS	Several	Offers services using push or crawler cameras to conduct remote visual inspections in confined spaces
Brokk Norge AS	Ski	Manufactures remotely controlled demolition robots.
Butler Solutions AS	Jørpeland	Integrator of automation and robotics solutions, including distribution of Nipper AGV (intelligent pallet truck) and mobile cleaning and disinfecting robots from BlueBotics.
Halodi Robotics	Moss, Oslo	Aims to design and develop safe and capable robots for human spaces. Initial targeted markets include security, retail, logistics and healthcare. Delivery to pilot customers planned for end of 2022.
Honeywell AS	Asker, Drammen	Integration of mobile robots mainly aimed at logistics and warehouse applications
Intek Engineering AS	Raufoss, Hamar	Develops and manufactures and integrates robots, software and automation for a variety of industries.
Kamelon Gruppen AS	Åros	Da deliver integrated solution with Universal Robots arm installed on a mobile robot as a "complete solution of pick&place and internal logistics".
Kilter AS	Langhus	Develops autonomous light-weight precision weeding robot that sprays only where it detects unwanted species. No systems delivered yet, but it is possible to register for a waiting list.

[26] https://new.abb.com/news/detail/95036/prsrl-abb-rebrands-autonomous-mobile-robot-portfolio

Knapp AS	Sandvika	Integration of industrial robot solutions for various processes in production and the warehouse including autonomous mobile robots for transport tasks.
nLink	Sogndal, Oslo	Designs and develops mobile robotic concepts and prototypes and also develops cloud robotics software and AI.
Nordic Unmanned	Sandnes	Manufactures the Staalker rail rover that integrates both an Unmanned Ground Vehicle (UGV) and Unmanned Aircraft System (UAS) for railroad inspection purposes.
Oceaneering AS	Several locations in Norway	Oceaneering Mobile Robotics designs and manufactures solutions based on autonomous mobile robot technology for logistics purposes.
Omron Electronics Norway AS	Several locations in Norway	Manufacturer of industrial robots, including autonomous mobile robots carrying payloads up to 1500kg.
RobotNorge AS	Klepp Stasjon	Integration of mobile robots from Rocla AGV, MAXAGV and Omron mainly aimed at logistics and warehouse applications.
Roboxi	Sandnes	Develops wheeled robot for runway inspection. Development contract with Avinor runs through 2024.
Saga Robotics	Oslo	Manufactures Thorvald, an autonomous multi-functional robot capable of controlling powdery mildew through UV-C treatment. It can also be used for other autonomous tasks. Thorvald services can be pre-ordered now.
Skala Robotech	Lierstranda	Develop custom machinery and solutions, including integration of industrial robots (mostly from Yaskawas MOTOMAN)
Smartshift Robotics AS	Hønefoss	Manufactures robotic add-ons for increased flexibility and productivity, including robot base and tool changer to fit most industrial robots/cobots.
Swisslog AS	Oslo	Integrators of industrial automation and robotics mainly focusing on warehouse logistics. Manufactures automated storage shuttle system for pallets. Also, the largest integrator of the AutoStore solution.
wheel.me AS	Oslo	Manufactures autonomous omni-directional wheels offered as a service. 4 wheels can carry 400 kg, and the max configuration of 12 wheels can carry 1200 kg.
Yeti Move AS	Kongsberg	Develops autonomous solutions for vehicles operating in controlled environments, including autonomous, fleet-operated snow clearing vehicles.

3.3.3 Providers relevant for Legged Robots

No relevant companies focusing on legged robot technologies were found in Norway.

3.3.4 Providers relevant for Snake Robots

Eelume AS provides an underwater vehicle that could be seen as “snake like” and more information about the company can be found in the next section on underwater robots (Sec. 3.3.5). No other relevant companies focusing on snake robotics were found in Norway. However, in an EU project called INACHUS[27]

27

SINTEF has developed a snake like tracked robots for search and rescue that could also be adapted for I&M operations.

3.3.5 Providers relevant for Underwater and Surface Robots

Norway-based providers particularly relevant for ***Underwater and Surface Robots***		
Company	**Location**	**Brief description**
Aersea AS	Kristiansand	Aerial and underwater survey and inspection services, utilizing multiple RPAS and ROV associated payloads. Includes inspections of power lines, railways, bridges, wind turbines, towers, offshore structures, pipelines, mapping, ortho photos, 3D scanning.
AKVA Group Sperre ROV Technology	Notodden	Develops ROV systems for offshore use, underwater inspection, maintenance and control of installations at depth of up to 10 500 meters. Also develops net cleaning solutions for aquaculture.
Argus Remote Systems	Bergen	Manufactures electrical ROVs, focus on oil and gas industry, subsea power cable industries, research institutions and aquaculture.
Blueye	Trondheim	Develops underwater drones with grippers, sonars, cameras, and navigation tools to be used in a wide range of industries, such as aquaculture, research, construction and inspection services.
Data Respons Solutions AS	Høvik, Skedsmokorset	Designs, develops and delivers smart embedded and industrial IoT solutions collaborating with leading technology partners. Previous work includes AUV technology systems and solutions and ROV controllers and sensors.
DeepOcean	Oslo	Operates over 50 ROVs. Manufactures tools in-house.
Eelume AS	Trondheim	Development of flexible, modular and slender autonomous resident robot for Inspection, Maintenance and repair of subsea installations.
Envirex		Develops customized robotics solutions mainly for subsea (specifically involving Titanrob manipulator series) but have also collaborated with AF Decom to develop the Decom X demolition robot
IKM Subsea AS	Bryne	Develops and uses electric workclass ROVs and residential ROVs, long experience using developing electric ROVs.
Innova AS	Sandnes	Integrator of ROV systems and ROV equipment including ROVs from Forum and Sub-Atlantic as well as subsea manipulators from Schilling Robotics.
Jotun	Several	The Jotun Hull Skater Solution is in the final stages of verification. The robot is designed to perform proactive cleaning of ship hulls without damaging the antifouling. Developed in collaboration with Kongsberg, Semcon, DNV GL, Telenor, Wallenius Wilhelmsen.
Mainstay	Sollihøgda	Develops robotized cleaners for the aquaculture industry, including net cleaners and tank cleaners.
Maritime Robotics	Trondheim	Design and manufacture of several types of unmanned surface vehicles (Mariner, Mariner X and Otter) aimed and surveying and other applications. Also offers a conversion system that allows manned vessels to be converted into unmanned vessels.
Kongsberg Maritime AS	Kongsberg and other	Development and manufacture of HUGIN series AUVs and the Sounder USV.

Kongsberg Ferrotech AS	Kongsberg	Delivers a range of inspection methods, from visual inspection to NDT technologies integrated in underwater robotics.
Oceaneering AS	Several locations in Norway	Subsea well intervention and ROV technologies
OceanTech Innovation AS	Trondheim	Develops unique robotics technology and operates as a service provider of robotic solutions for splash zone operations, especially for underwater cleaning, inspection, repair and modification services
Ocein (Ocean Innovations)	Kristiansund	Developer of StealthCleaner, a patented net cleaning and inspection too for nets used in aquaculture fish farms.
Posicom	Drammen	Provides video and image managing systems for surveys and inspections with automatic reporting capabilities.
Remora Robotics	Stavanger	Develops an autonomous net cleaning and inspection robot.
Remotion	Sandnes	Develops magnetic remote-controlled vehicles for offshore splash zone operations. Currently offers a series of 6 unique systems.
Skarv Technologies	Trondheim	Delivers software- and hardware-solutions for autonomous robotic systems operating in the marine environment.
TechnipFMC	Lysaker	Manufacturer of advanced remotely operated vehicles (ROVs) and manipulator arms (Schilling Robotics manipulator systems).
Troll Systems AS	Bodø	Develops robotics (e.g. for cleaning etc.) for land-based aquaculture facilities.
Watbots	Sandnessjøen	Develops patented autonomous robot to clean and inspect both sides of a submerged net aimed at aquaculture installations. Accepting pre-orders.
Østerbø	Frekhaug	Develops Yanmar Net cleaner, a submergible robot for cleaning fish farming nets.

3.3.6 Providers relevant for Aerial Robotics

Norway-based Providers particularly relevant for ***Aerial Robotics***		
Company	**Location**	**Brief description**
Acal BFI Norway	Hønefoss	Technology developer that works with customers to enhance their product particularly on challenges related to communications, magnetics, power supplies and sensors. Examples are error compensation for small drone INS system and helping to develop the world's first smartphone controlled gaming drone line.
Adapa 360	Oslo	Specialize in 360 content production and digital twins using custom designed camera rigs and drones.
Aersea AS	Kristiansand	Aerial and underwater survey and inspection services, utilizing multiple RPAS and ROV associated payloads. Includes inspections of power lines, railways, bridges, wind turbines, towers, offshore structures, pipe lines, mapping, ortho photos, 3D scanning.
Alva Industries AS	Trondheim	Develops electric ironless motor and propulsion systems based on patented fiberprinting technology. Propulsion system for industrial multirotor drones is currently available.

Aviant AS	Trondheim	Develops solution for fully automatic drone delivery, including landing platforms and home delivery service app (Kyte).
Axess AS	Several	Provider of drone inspection services
Biodrone	Steinkjer	Drone service provider that specializes in forestry and agricultural applications including aerial mapping, sowing, spraying, fertilizing.
Bouvet	Several	Develops software solutions and integrates hardware.
Data Respons Solutions AS	Høvik, Skedsmokorset	Designs, develops and deliver smart embedded and industrial IoT solutions collaborating with leading technology partners. Previous work includes obstacle tracking systems for aircraft and Systems and solutions for drones, robots and ROVs
Field Group	Several	Merger of KVS Technologies, Terratec and Sevendof. Main focus is to combine software, advanced sensors, and autonomous technologies to capture, process, and visualize data in a meaningful way. Develops long-distance drones and supporting ground infrastructure.
Haawk.ai	Oslo	Develops AI, edge, and robotics solutions for aerial Inspection of Energy Infrastructure.
Honeywell AS	Asker, Drammen	Development and production of flight Avionics and propulsion systems for drones and Urban Air Mobility systems.
Maritime Robotics	Trondheim	Designs and manufactures the customizable fixed-wing drone Falk and the moored balloon system Ocean Eye.
Nordic Unmanned	Sandnes	Manufactures and delivers high-end aerial drones, drone services and data capture solutions aimed at Maritime, Defence and Security, Offshore Logistics and Rail-services applications
Orbiton AS	Borre	Provider of industrial drone services for inspection and mapping.
Orbits	Sandefjord	Provider of systems for management and analytics of drone-enabled data.
ProXpect drones	Lier	Provides (typically drone-collected) inspection services, particularly focused on data processing (e.g. AI and deep learning) to provide automated maintenance backlog for assets.
Robot Aviation AS	Hønefoss	Developer of fixed-wing and VTOL UAS for military and commercial applications.
Scout DI	Trondheim	Manufactures tethered drone system designed for inspection of confined spaces and indoor industrial assets.

3.3.7 Norway-based End Users currently pursuing robots for I&M applications

In this section we summarize Norway-based end users that are pursuing robotics for I&M applications and are known to the authors, but the list is by no means complete. Note that companies that use robots as part of the production line are not included.

Norway-based end users currently using or pursuing I&M applications	
Company	**Examples of relevant initiatives within Robotics I&M**
Aker BP	• Working with Remotion to develop robots that can wash, water-jet, sandblast and paint the sides of ships. • Collaboration with Cognite to explore uses of Boston Dynamics Spot robot • Collaboration with DeepOcean and Forssea Robotics (French company) to develop the underwater Autonomous Inspection Drone (AID).

Aneo	• Starting to build up an in-house aerial drone organization for inspection and maintenance purposes.
Alta Kraftlag	• Partner in "Connected Drone" NFR project for drone inspection of powerlines and associated infrastructure (2015 – 2018).
Avinor	• Using self-driving runway sweepers developed by Yeti Move at Oslo Airport • Development contract with Roboxi for the prototype of a runway inspection robot.
Bane Nor	• Bane Nor has been testing a drone to grease track switches. Development continued by the startup Railway Robotics. • A 4-year contract to perform drone inspection of the railroad infrastructure of Bane Nor was signed with Nordic Unmanned in 2021.
Equinor	• Purchased Scout 137 Drone System from ScoutDI to perform tank inspection. Demo was held at Mongstad in 2022. • Active in investigating mobile robots for operations on offshore and onshore topside installations. • Collaborates with Kongsberg Maritime and Eelume to develop the subsea resident drone Eelume to perform inspection and light maintenance activities.
Gassco	• Using the small magnetic robot Bike for pressure vessel inspection at Kårstø and Nyhamna.
Glitre Nett	• Increasingly relies on drone service providers to inspect the powerlines. • In 2023 the entire 5300km infrastructure will be inspected using drones.
Gudbrandsdal Energi Nett	• Partner in "Connected Drone" NFR project for drone inspection of powerlines and associated infrastructure (2015 – 2018).
Hafslund Nett	• Partner in "Connected Drone" NFR project for drone inspection of powerlines and associated infrastructure (2015 – 2018).
NVE	• Mapping of areas for flood and avalanche management and disaster handling.
Ringeriks-Kraft Nett	• Partner in "Connected Drone" NFR project for drone inspection of powerlines and associated infrastructure (2015 – 2018).
Shell	• In 2016 Shell launched Sensabot as the first resident mobile robot certified to work in difficult and hostile environments. • Globally, Shell has been using drone technology since 2012 and uses drones to collect inspection data of out of reach spaces and large geographic areas.
Solgrid	• Starting to perform fault detection of their solar power plants using drones rather than using a handheld camera as previously.
Statens vegvesen	• Used drone technologies since 2014, with activities increasing significantly around 2018. Used for mapping, avalanche monitoring, road accidents and bridge inspections. • NFR project GEOSFAIR applies drones with camera, radar and laser scanner to collect data about the risk of avalanches. Collaboration with SINTEF and NGI. • Interested in new technologies including robotics for various infrastructure including tunnels, bridges and roads.
Statkraft	• Have in-house drone pilots but are looking for service providers that can offer aerial inspection services on a global scale for all Statkraft infrastructure.
Statnett	• Project with Field Group (previously KVS Technology), Nordic Unmanned and SINTEF to develop an automated drone prototype for inspection of electrical substations (2017 – 2019). • Will receive the DJI Dock (as the second company in Europe) and will use it to further explore the drone-in-a-box requirements and opportunities.

SINTEF

Telenor	• Partner in "Connected Drone" NFR project for drone inspection of powerlines and associated infrastructure (2015 – 2018).
Tensio TS	• Rely on drone service providers to inspect the powerlines.

4 Results of the Information Gathering

4.1 Summary of survey participation

It proved challenging to obtain responses to the surveys that are described in Sections 2.2 and 2.3. As shown in Table 3, 10 distributions of the End User survey resulted in 3 responses. Similarly, 34 distributions were made of the technology and service provider survey and 9 responses were received. The responses received to the surveys are very much appreciated by the authors. But due to the low response rate, the survey can only be used to collect useful observations and inputs from the participants and cannot be used as a basis for statistical analysis methods.

Type of Survey Recipients	Number of surveys distributed	Number of responses received
End user	10	3
Technology and service provider	34	9

Table 3: Summary of Survey Participation

4.2 Key findings from End User survey

The most critical insights to gather to help the uptake of I&M robotics solutions is to fully understand the detailed technical needs, as well as the associated regulatory, operational and financial constraints, of potential end users. Key feedback from the End User Survey is summarized in Table 4.

Description of End User feedback
Current applications of robotics include: - Blasting and painting interior and hard-to-access spaces - Aerial drones for inspections and surveys of infrastructure - Robots for welding of small aluminium bridges (pilot activity)
Major advantages using robotic solutions: - No need to stop traffic or shut down operations to perform the inspection. - Inspection using aerial drones are cheaper and faster than alternatives like use of scaffolding or lifts assuming you have trained personnel. - Offers access into spaces that are not otherwise possible to survey. - Benefits in terms of employee health and safety.
Desired improvements to existing robotic technologies include**:** - More effective solutions for outdoor painting. - Automatically identify damage using AI. - Autonomous data capture with drone for challenging construction geometries (bridges). - Increased operational efficiency. - More data available for learning and improving (AI, trending).
The biggest obstacles hindering a more widespread use of I&M Robotics Solutions: - The limited solutions that are available in the market - The ability of the solutions to solve all the cases where we have challenges and not only in easily accessible areas. - Development of specialized solutions require a large market potential to generate a profit, i.e., some markets are too small. - Lack of competence in the End User organizations. - Adaption of company culture and change (new roles). - Current levels of reliability and accuracy. - Data storage and user functionality.

Applications that may be promising to robotize: - Robotic solutions for Corrosion Under Isolation (CUI). - Additional robotic solutions for confined spaces or work at height. - Maintenance work such as water jetting, painting and cleaning. - Inspection with use of contact-based drones. - Drones for inspection of bridge condition.

Table 4: Summary of key feedback from the End User Survey

4.3 Key findings from Technology and Service Provider survey

Many companies that develop or take-into-use new robotic solutions aimed to address I&M applications are either startups or SMEs that may not have the financial muscles, expertise, nor the test infrastructure to cover the complete development and/or demonstration chain for the technology innovation in-house (e.g., without external financing). By identifying the biggest pain-points/hurdles that many of these companies face and identifying ways to alleviate these early in the development process, more companies may have success in meeting actual customer needs and bringing their products or service to the market. Also, if some of the risk associated with product development is eliminated, more people may be willing to form startups and attempt to bring their ideas to fruition. Key feedback from the technology and service provider Survey is summarized in Table 4.

Description of End User feedback
Top improvements or new features that providers are currently working on or are looking to implement: - Improved inspection technology for robotic solutions in the splash zone. - New robots to enable advanced movements and detailed work in harsh sea conditions. - New types of payloads for standard off-the-shelf aerial drones. - Collection of new training data and automated data analysis. - Cameras that adopt machine learning and classification of videos for automatic detection of findings. - Improve the performance of sensors for aerial drones to further advance the capability of these systems. - Autonomous feature recognition and data collection for unmanned surface vehicles and aerial drones. - Indoor navigation for aerial drones. - Extend the battery life for aerial drones. - Increase the level of autonomy for the robotic system. - Smarter solutions closer to the data (e.g., Edge AI). - More near-real time sensor data communication.
Lessons learned "the hard way" when bringing the robotic solution to the market: - It is critical to do relevant market research up front, to focus the development on applications with high customer value. - Secure more funding at the start, to be able to scale faster. - Start small scale. - Start with more capital that you think you need.
The biggest obstacles new technology/service providers face when trying to bring new I&M robotics solutions to the market: - Existing supplier contracts and network. - End user willingness to test and invest in new technology for long term payback. - To find the correct market price for a new service. - Market uptake.

- Getting benchmark testing and actual work to prove the solution works competitively. - Internal funding to explore new solutions. - Access to risk capital. - Adoption of new technology within bigger companies. - The ability of providers to scale up the capacity. - The lack of knowledge, conservatism, and unwillingness to change for End Users.
The type of desired support from external entities such as research groups and universities: - Clear information of the type of support that is available is a good first step. - Easier access to the available support. - Lower rates for startups. - More market orientation - less technology. - Provide access to benchmarking. - Provide contracts where "job done" is paid but attempts at new technologies is allowed. - Be bridge builders between various sectors and be more visible in the market promoting this function. - Actively propose project and funding opportunities and do the heavy lifting on the application side.

4.4 Discussion of Survey Results

The survey participation was lower than hoped for, but still generated some interesting input to steps that can be made to ensure more widespread use of robotics in Norway.

Initial feedback from industry indicated that an online survey taking only a few minutes would be the best option to ensure sufficient responses given the available resources (i.e., not possible with physical interviews). However, it proved more difficult than anticipated to reach a relevant person with competence and confidence to answer the survey on behalf of his/her organization. This is particularly valid for the end user organizations.

In general, the **End Users are pleased with the robotic technology** they are using currently, but point to **increased ruggedness, reliability and accuracy as key areas of improvement for robotic systems**. Furthermore, they **view automated data analysis as an enabler for increased value generation and more widespread use.** End Users recognize that they are struggling with challenges related to lack of competence related to the new technologies, that **company culture must be adapted and new roles defined.**

The technology and service providers report to be working on most of the challenges that End Users identify as these problems are fairly well known by now. **Automated data analysis is the most mentioned improvement that technology and service providers are working on**. Providers report that the **most critical challenge they face is to secure sufficient funds**. They would like external assistance to help to locate and secure relevant funding sources, to **gain the necessary understanding of the market situation**, to assess their systems in the form of benchmarking or similar and to be "bridge builders" between different sectors.

5 Summary and Conclusions

In this report, we review the current state-of-the-art in I&M robotics technologies, identify key Norwegian stakeholders and gather insights from relevant stakeholders. The culmination of this effort is the proposed series of strategic measures aimed at cultivating an environment conducive to the wider adoption of this transformative technology within Norway.

Increased End User Collaboration: Notably, Norwegian End Users demonstrate a prevalent inclination toward procuring existing robotics solutions rather than engaging in in-house development. While some entities prefer to purchase off-the-shelf solutions and independently manage the technology, the majority lean towards adopting Robotics-As-A-Service (RAAS) solutions. Organizing relevant meeting places such as seminars, webinars and workshops where End Users can get educated, stay updated and share experiences and lessons learned across companies and sectors will likely lead to a greater acceptance and trust in the robotized systems.

Elevated Emphasis on Workflow Integration: As the widespread integration of robotics necessitates substantial shifts in workplace culture and roles, attention must be devoted to initiating workflow adaptation at an early phase. This proactive approach will facilitate a smoother transition to the new technologies.

Precise Early Appraisal of Technological Potential: Prudent investments in robotics and their applications should be predicated on comprehensive market analyses and rigorous cost-benefit evaluations. A holistic perspective that encompasses the entire workflow is imperative. Merely automating singular tasks, while retaining the need for human intervention in other related functions, may not yield optimal returns. What is needed is to demonstrate time-bound potential return on investment (ROI) considering increased efficiency, reduced labor costs, and improved product quality.

User-Centric Solutions with Autonomous Data Analysis: A continued commitment to developing end-to-end solutions that include anomaly detection and decision support.

Target Scalable and Adaptive Solutions: By developing robotic solutions that can be conveniently scaled a small company is better equipped to accommodate changing production demands. A modular system approach allows the solution to be affordably customized to meet the needs of different industries.

Financial incentives and support to secure financing. The government can speed up the adoption of robotic solutions by offering targeted grants. Research institutions and universities can contribute significantly by identifying research gaps, identifying relevant grants, and orchestrating collaborations involving end users and technology and service providers.

References

1. Michael E. Moran. Evolution of robotic arms. J Robot Surg. 2007;1(2):103-11. doi: 10.1007/s11701-006-0002-x. Epub 2007 May 1.
2. Michal Bartoš, Vladimír Bulej, Martin Bohušík, Ján Stanček, Vitalii Ivanov, Peter Macek. An overview of robot applications in automotive industry. Transportation Research Procedia, Volume 55, 2021, Pages 837-844, ISSN 2352-1465, https://doi.org/10.1016/j.trpro.2021.07.052.
3. Pouliot, Nicolas, Richard, Pierre-Luc and Montambault, S.. (2015). LineScout Technology Opens the Way to Robotic Inspection and Maintenance of High-Voltage Power Lines. Power and Energy Technology Systems Journal. PP. 1. 10.1109/JPETS.2015.2395388.
4. Seetohul, Jenna, and Mahmood Shafiee. 2022. "Snake Robots for Surgical Applications: A Review" Robotics 11, no. 3: 57. https://doi.org/10.3390/robotics11030057.
5. Solheim, A. V. (2019). *Transportation for deep sea mining using underwater vehicle: Conceptual design using a systematic approach* (Master's thesis, NTNU).
6. Hutson, Matthew. (2017). Searching for survivors of the Mexico earthquake—with snake robots. Science. 10.1126/science.aaq1195.
7. Wanasinghe, Thumeera & Gosine, Ray & De Silva, Oscar & Mann, G.K.I. & James, Lesley & Warrian, Peter. (2020). Unmanned Aerial Systems for the Oil and Gas Industry: Overview, Applications and Challenges. IEEE Access. PP. 1-1. 10.1109/ACCESS.2020.3020593.
8. Shahmoradi, Javad, Elaheh Talebi, Pedram Roghanchi, and Mostafa Hassanalian. 2020. "A Comprehensive Review of Applications of Drone Technology in the Mining Industry" Drones 4, no. 3: 34. https://doi.org/10.3390/drones4030034.
9. Mahajan, Ar.Gayatri. (2021). Applications of Drone Technology in Construction Industry: A Study 2012-2021. International Journal of Engineering and Advanced Technology. 11. 224-239. 10.35940/ijeat.A3165.1011121.
10. Croon, Guido & De Wagter, Christophe. (2018). Challenges of Autonomous Flight in Indoor Environments. 1003-1009. 10.1109/IROS.2018.8593704.

A Surveys

A.1 End User Survey

Norwegian Inspection and Maintenance Robotics End User Survey

* Required

1. Which company do you represent in this survey?
   (The information will be used to ensure that we collect only one response per company)

2. How will you characterise your company? *

   - ◯ Startup
   - ◯ SME
   - ◯ Large Company
   - ◯ Public / Governmental / Military agency
   - ◯ Other

4. Which I&M robotics solution(s) do you use currently?

5. What works well with the current solution(s)?

6. What are the top improvements you would like to see for the current solutions(s)?

7. Can you give some idea/measure of how successful it has been for your company to adopt the currently used I&M robotics solution(s)?

8. Which one of the following applies to your company: (select all that applies)

- ☐ Currently investing or looking to invest in the development of new I&M robotics solutions to fit the specific needs.
- ☐ We have or are currently participating in a EU-funded or nationally funded research project to develop relevant I&M robotics solutions.
- ☐ Own (or looking to purchase) off-the-shelf I&M robotics solutions.
- ☐ Purchasing or looking to purchase I&M robotics as a service.
- ☐ Not considering use of I&M robotics at all

9. What do you feel are the biggest obstacles hindering a more widespread use of I&M Robotics Solutions?

10. Describe an existing application in your industry that seems promising to robotize.

11. Indicate your level of interest in the suggested solution. (select all that applies)

- ☐ We are interested in investing funds in the development of the technology if a promising solution is presented.
- ☐ We are interested in participating in a EU-funded or nationally funded research project to develop a promising solution.
- ☐ We will purchase the solution when it is market-ready.
- ☐ We will are interested in subscribing to a robotics-as-a-service solution when it becomes available.
- ☐ We are really not considering the use of any I&M robotics solutions at this time.

12. What are (in your opinion) the biggest challenges with respect to robotizing this application?

A.2 Technology and Service Provider Survey

Norwegian Inspection and Maintenance Robotics Technology Provider Survey

* Required

1. Which company do you represent in this survey?
(The information will be used to ensure we only collect one response per company)

2. How will you characterise your company? *

- ◯ Startup
- ◯ SME
- ◯ Large Company
- ◯ Other

3. My company can be mentioned as having contributed to the market study. (The details of the response will not be linked to the company in the presentation of the market study). *

- ◯ Yes
- ◯ No

4. What type of I&M robotics solutions do you provide currently? (Enter "None" if you currently do not have any solutions on the market) *

5. What works well for this/these solution(s)

6. What are the top improvements or new (potentially customer-driven) features you would like to implement for this/these solution(s)?

7. Do you foresee wanting to collaborate with others to address further technological development of your product or service? If so, what competence would be most relevant?

8. What are existing and potential customers? You can refer to type of company or sectors (e.g., Hydropower companies) rather than company names if you prefer.

9. Is the robotic solution considered a success for your company?

10. Based on what you learned in the process of bringing the robotic solution to the market, what would you do differently if you were to do it all over again?

11. Which one of the following applies to your company:

- ☐ Currently developing and/or selling off-the-shelf I&M robotics technology.
- ☐ Currently offers I&M services using robotics.
- ☐ Currently working to bring our first I&M robotics technology to the market.

12. What do you feel are the biggest obstacles new technology/service providers face when trying to bring new I&M robotics solutions to the market?

13. How can external entities (e.g. research groups, universities, other) provide better services to help new technology/service providers succeed in bringing their innovations to the market (e.g. provide access to infrastructure/equipment, provide benchmarking / validation services, providing funding advice etc.)?