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Report

RINVE Feasibility Study 2018

Understanding End User Demands, Supplier Capabilities and Technology Gaps related to Automation and Robotics in Inspection and Maintenance

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ABSTRACT

Abstract heading

This report summarizes end user needs and supplier capabilities within the "Automation and Robotics for Inspection and Maintenance" (RINVE) Network as identified in an innovation workshop held on the 10th of April 2018 at Gardermoen and a follow-up survey that was completed by the supplier companies in the network. The end user sectors considered in this report include:

- Bridge inspection and maintenance
- Railroad inspection and maintenance
- Airport inspection and maintenance
- Offshore inspection and maintenance

The main purpose of the report is to serve as inspiration for new commercialization, research and development initiatives in Norway tied to the use of automation and robotics for inspection and maintenance work.

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0.9	2018-08-29	Final draft for Quality Assessment. Minor revisions to Luminell and Aersea content. Added input from Alva Motor Solutions.
1.0	2018-09-25	Final version. Minor changes following Quality Assessment process.

Executive summary

This report summarizes RINVE-Network end user needs and supplier capabilities related to the use of automation and/or robotics in inspection and maintenance. The work is based on an innovation workshop held on the 10th of April 2018 at Gardermoen and a follow-up survey that was completed by the supplier companies in the network. The main goal is to stimulate new activities in Norway tied to the use of automation and robotics for inspection and maintenance work, thus the report attempts to identify promising new applications of this technology. Based on input from the end users, the following four candidate sectors for increased use of automation and robotics will be explored in more detail in this report:

- Bridge inspection and maintenance
- Railroad inspection and maintenance
- Airport inspection and maintenance
- Offshore inspection and maintenance

All these sectors are using automation and/or robotics to a varying degree already, but primarily only for certain types of inspection missions. The workshop, the follow-up survey responses as well as a very brief survey of existing technologies resulted in a list of opportunities for each of these sectors as summarized in the following table.

END USER SECTOR	DESCRIPTION OF OPPORTUNITY
ALL SECTORS	<p>Automate the Analysis of Inspection Data For the automatic inspection to be truly useful, the output generated should not be a large dataset that requires human interpretation, but rather be high-level results that includes degree and extent of a damage, type of damage, cause of damage, consequence of damage and that also concludes on required actions/follow-up. Some enhancements to the inspection tools may be required in order to make reliable classifications, such as the possibility of measuring the thickness of paint/coatings by touching the relevant place with a probe.</p>
Bridge IM	<p>Develop a Unmanned Aircraft System (UAS) Service Network Concept The high frequency of bridge inspection within certain areas warrants consideration of a concept where a small number of autonomous drones, a drone network, can serve as inspectors to a large number of bridges within reach of the drone network. The network may consist of several (preferably autonomous) base stations or drone garages where the drones can be stored, charged and can upload/download data. The drone network should be planned such that the drones avoid flight over densely populated areas and roads. Flying over rivers etc, may be a good option. Also, there should be redundancies in the system such that each bridge can be reached from more than one base station. The drone network should be monitored by a manned control centre.</p>
	<p>Improve the Robotic Maintenance Capability It is of particular interest to develop robotic tools suited to blast and paint/coat bridges without having to put up scaffolding and without impacting the traffic on the bridge.</p>
Railroad IM	<p>Develop a UAS Service Network Concept Similar to what is suggested for Bridge IM. In this case, the flight paths could follow the railroad tracks.</p>
	<p>Develop Automatic Foreign Object Detection and Removal Solution</p>

	<p>The ability to automatically detect and remove hazardous foreign objects/debris/shavings (possibly also ice) away from the tracks and switches. This is preferably done using a UAS to avoid disrupting the train traffic.</p>
	<p>Improve the Robotic Maintenance Capability It is of particular interest to develop robotic tools for lubrication of switches. UAS technology is most relevant to avoid disrupting the train traffic.</p>
<p>Airport IM</p>	<p>Develop an UAS "Grounds Keeper" Concept As Avinor is at the forefront in the world in the development of the remote towers concept, this offers a good opportunity for the Norwegian technology suppliers to enter into a collaboration to develop a robust UAS system specifically suited as a resident "grounds keeper" at this type of facility but also for other small airports that requires cost-effective solutions. Tasks should include inspection of runway and other critical structure, removal of small objects on the runway and scaring off birds and other wildlife. A "robot team" that involves both UAS and ground robots could relieve many of the inspection tasks which are carried out manually today. The robots will need a ground station or drone garage similar to what is described under Bridge IM Drone Service Network Concept.</p>
	<p>Develop Automatic Foreign Object Detection and Removal Solution Similar to what is suggested for Railroad IM, where the primary objective would be to detect and remove small objects from the runway. Some type of wheeled robot may be advantageous in case larger items need to be removed.</p>
	<p>Develop Concepts for Automatic Area Surveillance and Threat Mitigation Safe airport operations depend on the ability to keep undesirable vehicles/persons/animals away from the premises. The ability to automatically detect, classify and deter undesirable activities will help to provide the situational awareness and control that is desired, particularly in the remote towers concept. For instance, UAS have been used successfully to mimic predator birds to help scare birds away from the vicinity of the airport.</p>
<p>Offshore IM</p>	<p>Develop a UAS and Unmanned Underwater Vehicle (UUV) "Grounds Keeper" Concept Similar to what is suggested for Airport IM, however, UAS would be developed primarily for use at unmanned offshore facilities and will likely need to be ATEX certified.</p>
	<p>Improve the Robotic Maintenance Capability It is of particular interest to develop robotic tools for blasting and painting/coating offshore structures without having to put up scaffolding and also to develop automated solutions for performing inspection underneath insulation or equipment without having to remove it.</p>
	<p>Develop ATEX Approved Robots and Automatic Solutions For a robot or an automated solution to be able to operate in most areas of interest onboard a petroleum facility, the equipment has to be at least ATEX 1 certified.</p>

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List of Abbreviations

Abbreviation	Definition	Additional Description (if needed)
ADS-B	Automatic Dependent Surveillance – Broadcast	Surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it to allow tracking.
ATEX	(Appareils destinés à être utilisés en ATmosphères EXplosibles)	The ATEX directive consists of two EU directives that describes equipment and work environment allowed in an explosive atmosphere.
AUV	Autonomous Underwater Vehicle	
BIA	Brukerstyrt InnovasjonsArena	A type of project from the Norwegian Research Council. (English: "End user guided innovation arena")
CR	County Road	
DFT	Dry-Film Thickness	
FOD	Foreign Object Debris	
FPSO	Floating Production Storage and Offloading	A type of floating vessel used by the offshore petroleum industry
GPS	Global Positioning System	
HMI	Human Machine Interface	
HW	HighWay	
IM	Inspection and Maintenance	
IP	International/Ingress Protection Marking	Classification/rating of the degree of protection provided against intrusion, dust, accidental contact, and water by mechanical casings and electrical enclosures. Covered in IEC standard 60529.
IPN	InnovasjonsProsjekt i Næringslivet	A type of funding from the Norwegian Research Council. (English: "Business Innovation Project")
LiDAR	Light Detection And Ranging	
NDT	Non-Destructive Testing	
RINVE	Automation and robotics in inspection and maintenance	A Norwegian Network with the main goal of contributing to starting new national activities tied to the automation and robotics in inspection and maintenance.
ROS	Risiko- og Sårbarhets-analyse	In English "Risk- and Vulnerability-analysis"
ROV	Remotely Operated Vehicle	
SVV	Statens VegVesen	Norwegian state highways authority
UAS	Unmanned Aircraft System	An UAS includes a UAV, a ground-based controller and a system for communication between the two. ¹
UAV	Unmanned Aerial Vehicle	
USV	Unmanned Surface Vehicle	
UUV	Unmanned Underwater Vehicle	

¹ https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle

1 Introduction

This section provides a brief description of the motivation and scope of this report as well as a presentation of the team behind it. The report is primarily based on a RINVE network innovation workshop held on 10 April 2018 at Gardermoen and a follow-up survey that was completed by the supplier companies in the network.

1.1 Project Motivation and Contribution

There is a constant need for inspection, surveillance and maintenance of large and/or complex industrial infrastructures. Traditionally, much of this work is performed manually, but the work can often be associated with dangerous, tedious and monotonous tasks and usually involves high labour costs. Therefore, this is regarded as a promising area for increased use of automation and robotics.

Some facilities have already started to introduce automation and/or robotics for certain types of work. An example from the petroleum industry is the inspection of flare towers by means Unmanned Aerial Systems (UAVs) which has proven to be very time- and cost-effective and is fast becoming the preferred industry method. The use of UAS for this application improves safety aspects as the need for having personnel work at great heights is greatly reduced or even eliminated. Removing the need to put up scaffolding and safety lines reduces costs and may mean avoiding a lengthy plant shutdown. Furthermore, as support structure is time-consuming to put up, the associated delay increases risk in time-critical situations. Thus, the potential of human and financial cost savings is great. Similar arguments can be made for other types of inspection scenarios, such as inspection of bridges, storage tanks and splash zones. In other industries it may be the size and/or the layout of the installation coupled with frequent inspection intervals that represent the major challenge, making human/manual inspection alone prohibitively expensive and also extremely tedious. Examples includes railroad and airport infrastructure.

An additional benefit of increased use of automation and robotics is the capability to capture a large amount of real-time data. High-resolution images or video captured by UAS will typically give better inspection coverage than possible by use of humans. The collected data also represents a valuable input into maintenance planning. Getting the most value out of the collected data is high up on the agenda for most end users.

The main goal of the RINVE network is to contribute to increased use of automation and robotics in the inspection and maintenance of infrastructure tied to Norwegian industry. This involves the following objectives:

- Identify companies that are relevant to the entire value chain.
- Establish collaborations across different fields.
- Expand the boundaries for marketing-, technology-, and application-possibilities.
- At a minimum, realize 3-5 IPN applications to BIA within 3 years.
- Communicate results and information to relevant parties across all fields and application areas.

1.2 Scope of this Report

The primary objective of this report is to summarize the current use of automation and robotics for inspection and maintenance purposes in key industrial sectors in Norway, and to identify promising new applications of this technology for each sector. The overall goal is to stimulate new activities in Norway tied to the use of automation and robotics for inspection and maintenance work.

1.3 The Team behind this Report

RINVE is a Norwegian network that aims to contribute to increased use of automation and robotics within industrial inspection and maintenance tasks. Per 29 August 2018, the network consists of the following members:

- **End Users:** Bane NOR, AkerBP, Equinor, Statens Vegvesen, Avinor.
- **Suppliers of Technologies and Services:** ATEA, Jotun, Oceaneering, Maintech AS, OceanTech, KVS Technologies AS, Surface Dynamics AS, Triple-S, Maritime Robotics, Simicon / Robot Inspect AS, SEVENDOF, FORCE Technology AS, Axess AS, PPG, Solid Vedlikehold, Versor, Nordic Unmanned, nLink AS, SINTEF Industry, AERSEA AS, International Paint, Opscom Systems AS, eSmart, Luminell, Alva Motor Solutions.
- **Research and Development:** Norsk Regnesentral, NTNU, SINTEF
- **Other:** Norges Forskningsråd

In addition, there is a cooperation between RINVE and Norwegian organizations such as Norsk Forening for Vedlikehold, iKuben and Vedlikeholdsnettverk Nord.

1.4 Acknowledgement

This project is partially funded by The Norwegian Research Council.

2 End User Demands

Based on input from end users, the following four candidate sectors for increased use of automation and robotics will be explored in more detail in this section:

- Bridge inspection and maintenance
- Railroad inspection and maintenance
- Airport inspection and maintenance
- Offshore inspection and maintenance

It will be clear from the next sections that all these sectors are using automaton and/or robotics to some degree already, but the degree of automation employed varies.

2.1 Bridge Inspection and Maintenance

The information contained in this section is derived primarily from input from Statens Vegvesen (SVV) and a very brief review of current and emerging Bridge IM technologies.

2.1.1 Description of Infrastructure and Relevant IM Requirements

SVV is per April 2018 responsible for the condition of 17,568 bridges and ferry piers, with a total length of 470 km. About 9,600 bridges have a span of less than 10 m, while about 882 bridges have spans exceeding 100 m. The average age of the bridges included in the Highway (HW) system is about 35 years, while the average age of the County Road (CR) bridges is about 47 years.

There are 4 different bridge inspection types with different inspection intervals, and these are summarized in Table 1.

Table 1: Bridge Inspection Types and Requirements

Inspection Type	Inspection Frequency		Inspection Requirements (Details in "Håndbok V440" and "Håndbok V441")	In Brutus?
General Inspection	HW: Weekly	CR: Every 2 weeks	<ul style="list-style-type: none"> - Performed by operating contractor. - Typically performed by slowly driving across. - Findings need to be reported, no other documentation required. 	No
Simple Inspection	Annually ²		<ul style="list-style-type: none"> - Inspectors must have bridge expertise. - Mainly visual inspection to look for changes/concerns. - Scaffolding not required - Required to register damage that needs repair/attention prior to the next simple or main inspection. 	Yes
Main Inspection	Movable bridges and ferry piers: Every 3 years ³ All others: Every 5 years ³		<ul style="list-style-type: none"> - Inspectors must have expertise on that particular type of bridge. - Register all damage to the bridge - Scaffolding is often required - Required measurements and sampling - Register suggested maintenance 	Yes
On-Demand Inspection	On demand		<ul style="list-style-type: none"> - Special inspections may be required after event like floods, collision etc. 	

The following list provides additional details about important aspects of a bridge inspection that must be considered:

- Each damage to be classified into type(s) of damage.
- Evaluate the degree/level of damage and the extent of the damage.
- Consider the cause(s) of the damage.
- Evaluate how serious the damages are to the entire bridge construction and also the surroundings, i.e. the consequence of the damage tied to the categories; load carrying capacity, traffic safety, maintenance and environment/aesthetics.
- Conclude on required actions/follow-up.

Brutus is an electronic management tool used to track the condition of bridges. The tool is used to:

- Store architectural and structural data, descriptions, load carrying capacity and safety management.
- Plan, register and store data from bridge inspections.
- Register, plan and prioritize actions/maintenance activities.

2.1.2 Current use of Automation/Robotics in Bridge IM

The inspection of bridges represents an emerging use-case for capable and robust UAS solutions, as such inspection eliminates the need for scaffolding/rigging, thus effectively reducing cost and increasing safety. An additional benefit of this technology, compared to many alternative ones, is that the bridge can be inspected without impacting the traffic on the bridge. SVV has been exploring the use of UAS for bridge

² Can be skipped following a ROS analysis

³ Can be modified to a max interval of 10 years following ROS analysis

inspections for a few years already⁴, but the technology can benefit greatly from an increase in the degree of autonomy both associated with UAV operation as well as the data processing and interpretation.

There is a growing interest worldwide in developing robots and automated IM methods that specifically targets bridges. While no complete review of available technologies has been made as part of this study, a few examples of emerging technologies include the bridge inspection robots developed by Infrastructure Preservation Corporation (IPC) shown in Figure 1 and the SABRE Autonomous Bridge Blasting Robot shown in Figure 2. The latter has been extensively tested on the Sydney Harbour Bridge and two of these robots are now part of the permanent maintenance crew.



Figure 1: IPC CableScan - Robotic Cable Stay Inspection. Credit: IPC



Figure 2: SABRE Bridge Blasting Robot. Credit: SABRE Autonomous Solutions

2.1.3 Future Needs and Challenges related to Automation/Robotics in Bridge IM

Use of a robust UAS solution for bridge inspection purposes is expected to be increasingly common. Work will continue to increase in the degree of autonomy associated with UAV operation as well adopting "Big Data" techniques to enhance the data processing and interpretation. Depending on the bridge subject to

⁴ <http://www.newswire.no/art/10905>

inspection, the UAS may be able to cover most of the above-water inspection needs. However, there will likely be some portions of the above-water structure of many bridges that require additional inspection methods, either due to accessibility issues or simply because other methods are more suitable and/or efficient. For under-water structure UUVs with similar capabilities as UAVs are expected to dominate the future IM market.

A key challenge in developing automated solutions aimed at bridge inspection is that every bridge is unique. There can be major variations in size, type of structure, degree of accessibility and material selections from one bridge to the next, hence the solutions developed must be highly adaptable. Any drone developed for this purpose must be able to operate in GPS denied environments and be able to handle rain and challenging operating conditions.

2.2 Railroad Inspection and Maintenance

The information contained in this section is derived primarily from input from Bane NOR, a Norwegian state-owned enterprise with responsibility of all the Norwegian railroad infrastructure, and a very brief review of current and emerging Railroad IM technologies.

2.2.1 Description of Railroad Infrastructure and Relevant IM Requirements

The Norwegian railroad infrastructure consists of the following key elements:

- About 4209 km railroad, of which well over half has been electrified.
- About 3412 railroad switches.
- 336 railroad stations and 12 cargo terminals.
- About 733 railroad tunnels.
- About 2577 railroad bridges.



Figure 3: Railroad Infrastructure between Bergen and Fløyen. Credit: Silje Katrine Robinson

The inspection and maintenance tasks that were deemed most relevant to address using automation/robotics are summarized in Table 2.

Table 2: Railroad IM Tasks Relevant for Automation

Inspection /Maintenance Task	Relevant Details
Inspection of "Sporfelt" (a piece of track that is monitored for occupancy)	<ul style="list-style-type: none"> - A common problem is shavings that accumulates - Look for mechanical wear and tear of the tracks that may lead to problems.
Maintenance of "Sporfelt"	<ul style="list-style-type: none"> - Desire the ability to automatically remove objects/debris
Inspection of Switches	<ul style="list-style-type: none"> - Desire to identify if the geometric shape of a switch is correct. - In the winter chunks of ice can jam the switches. - Rocks or other foreign objects can (partially) jam or hinder correct operation of the switch. - Identify cracks, bolt flaws or other signs of mechanical failure of the switch and classify the condition.
Maintenance of Switches	<ul style="list-style-type: none"> - Lubrication of switches is a very boring task that requires precision. - Can operation be optimized by choice of different surface materials and/or lubricants? - A likely timeline toward automatic lubrication is to go from lubrication intervals every 2 weeks, to lubrication determined by friction level, to the ability to predict the "optimal" lubrication time, to a fully automatic lubrication process.
General inspection tasks	<ul style="list-style-type: none"> - A robotic system permanently installed, should be able to be flexible and to perform inspection/maintenance of a wide selection of subsystems such as power supplies and cables. - On demand inspection during problems/failures should be possible.

Per Bane NOR: " The hairy but achievable goal is inspection and maintenance in open time-slots in the train schedule during day-time when it is not deemed safe for humans to perform work. Bane NOR (often) has an available flight corridor above the train tracks that is always available, and a lot of inspection tasks can be done from there without worrying about train traffic. The benefit to society is great as we will be able to achieve cheaper and better train maintenance."

2.2.2 Current use of Automation/Robotics in Railroad IM

The inspection of railroad infrastructure represents another emerging use-case for capable and robust UAS solutions, as such inspection can be performed very efficiently and without disrupting the train traffic. Note that the discussion related to bridge IM in Section 2.1, also applies to the IM of railroad bridges, and Bane NOR has in fact started to use UAS for bridge inspection purposes⁵. In addition to standard inspection tasks, Bane NOR uses UAS for mapping and monitoring purposes during/after emergencies such as an avalanche, a landslide or flooding⁶.

Bane NOR has also started to explore the use of UAS for maintenance tasks. Earlier this year, they demonstrated the use of a UAS to lubricate a railroad switch as shown in Figure 4. Despite 10 m/s wind, Bane NOR reported (during the RINVE Workshop) that the UAS was able to reduce the friction in the switch significantly.

⁵ <http://www.banenor.no/Prosjekter/prosjekter/vestfoldbanen/farriseidet---porsgrunn2/innhold/2017/bruker-drone-til-bruinpeksjon/>

⁶ <http://www.banenor.no/Nyheter/Nyhetsarkiv/2018/flyvende-beredskap/>



Figure 4: UAS used for Lubrication of Railroad Switches. Credit: Harry Korslund

2.2.3 Future Needs and Challenges related to Automation/Robotics in Railroad IM

Due to the need to perform inspection and maintenance without disrupting the train traffic, a robust UAS solution represents the most promising robotics technology for railroad infrastructure. Again, these systems will need to become more autonomous both with respect to UAV operation as well as the data processing and interpretation.

2.3 Airport Inspection and Maintenance

The information contained in this section is derived primarily from input from Avinor, and a very brief review of current and emerging Airport IM technologies

2.3.1 Description of Airport Infrastructure and Relevant IM Requirements

Avinor is responsible for 45 airports across Norway. The relevant infrastructure includes:

- 47 runways.
- 84 approaches with obstacle-free zones.
- Approximately 85,000 m² asphalt/concrete-surfaced runways.
- About 43,600 runway/approach lights.
- About 150,000 m airport fencing.

Most of this infrastructure requires regular inspection and/or maintenance. The inspection interval at a runway exceeding 1200 meters requires 2 daily inspections. Shorter runways require one daily inspection. A particular challenge involves the task of keeping animals, particularly birds, away from the airport.



Figure 5: Røst Airport. Credit: Digitalt Museum

2.3.2 Current use of Automation/Robotics in AIS

Work to develop autonomous plow trucks was initiated by Avinor about 3 years ago, and a full-scale pilot system (shown in Figure 6) was successfully tested at Fagernes Airport on March 18, 2018. The system is being developed by Kongsberg-based Yeti Snow Technology AS and is, according to Avinor, the first project of this type in the world. Avinor aims to start rolling out the system to its 46 airports in the next year or two.



Figure 6: Test of Autonomous Plow Trucks at Fagernes Airport March 19, 2018. Credit: Avinor

Another ground-breaking project led by Avinor in partnership with its suppliers KONGSBERG and Indra Navia, is the Remote Towers project that aims to replace 15 airport towers and to remotely control the airport from a control centre in Bodø. The view out the windows from the current airport towers are effectively replaced by computer screens that displays 360-degrees real-time images of the airport (Figure 7).



Figure 7: Bodø Control center Displaying Approach into Røst Airport. Credit: Preben Hunstad

Advanced solutions for runway management is offered by a company called Xsight Systems. The key component "RunWize™" is collocated with the runway edge lights and uses a combination of optical camera and millimetre wave radar to detect Foreign Object Debris (FOD). Available enhancements to the system include:

- "SnowWize™" to allow remote measurements of real-time snow depth levels across the runway.
- "BirdWize™" for comprehensive runway ground level bird hazard management.

The system is in use at major airports including Seattle-Tacoma International Airport, Boston Logan International Airport and Paris Charles de Gaulle International Airport. In 2013, the technology was quoted as costing about \$5 million per runway⁷. Several alternative automatic FOD detection solutions are used at major airports worldwide, most of these involve a tower-structure with different sensors attached, including millimetre wave radars. Tarsier Automatic Runway Debris Monitoring System requires three such installations to cover a long runway and is in use at London Heathrow International Airport and Vancouver International Airport.

Clear Flight Solutions is developing a remotely controlled bird of prey called "Robird" (shown in Figure 8), which has been successfully tested at airports in Canada and England. The robot flaps its wings as means of propulsion and is developed in both a Peregrine Falcon and an Eagle version to have the ability to scare off most types of birds.

⁷ <https://www.bizjournals.com/boston/blog/techflash/2013/11/boston-logan-is-first-to-use.html>



Figure 8: Peregrine Falcon Robird. Credit: John Robertson/CBC

2.3.3 Future Needs and Challenges related to Automation/Robotics in Airport IM

The development of UAS to perform autonomous airport surveillance is already well underway. A successful system should be able to collect the desired data autonomously, transmit the data to a common data processing centre where maps can be updated and trends and warnings can be generated.

As Avinor is at the forefront in the world in the development of the Remote Towers concept, this offers a good opportunity for the Norwegian technology suppliers to enter into a collaboration to develop a robust UAS system specifically suited for operation at this type of facility.

Several challenges are tied to potentially difficult terrain or weather near/at the airport. Some potential problems include:

- Airport fencing can be located in hilly terrain, in a forest, in a swamp on a steep slope etc.
- Poor visibility due to snow/rain/fog/darkness.
- A lot of snow may make the accessibility of different infrastructure problematic.
- It must be possible to identify foreign objects with length/diameter down to 2 cm on the runway.
- Autonomous inspection of lights requires the ability to determine light intensity and direction.

2.4 Offshore Inspection and Maintenance

The information contained in this section is derived primarily from input from Statoil (today Equinor) and Aker BP, and a very brief review of current and emerging Offshore IM technologies.

2.4.1 Description of Offshore Infrastructure and Requirements

Today there are about 500 installations on the Norwegian Continental Shelf, divided into the following categories:

- 12 concrete facilities.
- 70 steel facilities resting on the sea bed.
- 21 steel floating facilities.
- Nearly 400 subsea installations.

Many of these installations are approaching the end of their expected lifespan⁸.



Figure 9: The Ekofisk Field has been in production since 1971. Credit: Conoco Phillips

Each facility typically contains the following structural components that poses inspection and maintenance challenges:

- Flare stacks.
- Cluttered environments due to space restrictions.
- The inside of tanks and pressure vessels.
- Surfaces covered by insulation.
- Under decks.
- Splash zones.

Furthermore, a petroleum installation has a very high inspection and maintenance work-load (due to safety requirements) for the number of people available, and much of the work is potentially hazardous or involve poor ergonomics and/or noise. To free up personnel and to relieve personnel of dull, dirty and dangerous work, the following types of work are good candidates for robotization:

- Sandblasting large surfaces.
- Cleaning large surfaces.
- Coating/painting large surfaces.
- Inspecting the detailed condition of large surfaces.
- Measure the thickness of coatings on large surfaces.

Cost is of course another consideration that must be made. The development or purchase of robotic equipment involve significant costs and must have a sound business case. It can be noted that the following measures typically lead to cost savings:

- Reducing the number of people that must be involved in the operation.
- Reducing the duration of the overall operation.

⁸ <https://www.norskpetroleum.no/utbygging-og-drift/avslutning-og-disponering/>

- Eliminating the need for scaffolding.
- Eliminating the need to shut down production.
- Avoid emergency shutdowns and/or urgent repairs by prioritizing the maintenance work based on (accurate) condition monitoring.
- Eliminating the need to remove equipment or insulation to perform inspection/maintenance.

2.4.2 Current use of Automation/Robotics in Offshore IM

Performing flare inspection with help from a Unmanned Aerial System has quickly become popular among petroleum facility operators worldwide. Cyberhawk alone has performed over 200 close visual and thermal flare inspections and surveys. A major benefit to UAS flare inspection is that it can be performed "live", i.e. production does not have to be shut down.



Figure 10: Live Flare Inspection. Credit: Cyberhawk

The mobile blast cleaning robot developed for bridges by SABRE Autonomous Solutions shown in Figure 2, is also advertised for use in marine confined spaces such as for ballast and storage tanks and pressure vessels. RINVE member Surface Dynamics have remote controlled robots that have performed inspection, pre-cleaning and blast-cleaning commercially, specifically their System-T shown in Figure 11 has been used to blast-clean the Åsgard A FPSO ballast tanks.



Figure 11: Surface Dynamics System-T. Credit: Surface Dynamics

Surface Dynamics report that they are working on making the systems more autonomous and also on adding painting and quality control capability.

2.4.3 Future Needs and Challenges related to Automation/Robotics in Offshore IM

Recent advances in robotics has offered great increases in the safety and efficiency associated with offshore inspection, and operators of petroleum facilities are highly motivated to achieve cleaning and painting tasks in a similar manner. Putting up the required scaffolding to perform these tasks manually, carries significant costs.

Remaining challenges associated with robotic systems for inspection includes:

- The robotic system must be designed to be sufficiently robust with the ability to operate in realistic offshore environments (temperature/winds/weather/saltspray/icing), including operations in the splash-zone.
- The robotic systems must be ATEX certified to be allowed to access all areas of an offshore installation. Many areas onboard a petroleum installation have an ATEX classification, indicating the risk of an explosive atmosphere. Zone 0 indicates areas where the atmosphere is always explosive, areas with an atmosphere that is frequently explosive are classified as Zone 1, and areas where hazardous gas or vapors are present on an occasional basis are classified as Zone 2. Very few robots have been certified for ATEX Zone 1. Beyond the robot arm "Telbot" developed by HWM⁹, we are not aware of any other robot systems that are certified for ATEX Zone 0.
- Develop robotic systems that can operate in GPS denied environments.
- Develop robotic systems that are capable of accessing and operating in tight spaces (for example underneath the deck of an offshore platform).
- Develop solutions for reliable navigation and operation onboard/at unmanned facilities, particularly with respect to HMI (decision support etc.). For instance, identifying shared use of sensor information.
- Develop/improve automated maintenance programs that combines available safety/integrity data with condition monitoring to determine maintenance intervals.

Some of the additional challenges that must be solved in order to develop robust robotic systems for cleaning/painting includes:

- Developing painting/coating systems that are feasible to use with a robotic system.
- Developing systems that are able to sandblast and paint submerged surfaces.
- Some maintenance work requires to carve out sediments as well as chiselling.
- While UAS represent the most versatile platform for many maintenance tasks due to ease of access, the weight and space constraints associated with UAS greatly limit their current capability.

3 Supplier Capabilities

This chapter summarizes the capabilities and interests of relevant Norwegian industrial suppliers of technology and services tied to the use of automation and robotics in inspection and maintenance work. The technologies and/or services have been sorted into the following *IM Support Categories*:

- Providers of inspection, maintenance and repair services.
- Suppliers of drones and drone technology.
- Providers of automation, digitalization and safety solutions.

It is important to note that this chapter is primarily based on input from the RINVE suppliers, either through the 2018 RINVE Workshop or through responses provided to the Supplier Survey presented in Section 3.1, and while the goal has been to mention all the key developments related to commercial drone technologies,

⁹ <https://www.hwm.com/atex-178.html>

the summary provided does not represent a complete review of all aspects of the relevant technologies or of all commercially available products.

In addition to the suppliers in RINVE, there are also three research organizations: NTNU, Norsk Regnesentral and SINTEF. These are not covered by the survey. The organizations can deliver know-how within areas such as image analysis, machine learning, autonomy, statistical analysis and control system design.

3.1 Supplier Survey

All the service and/or technology providers participating in the RINVE network were asked to complete a survey containing the questions listed in Table 3.

Table 3: Supplier Survey Questions

QUESTIONS TO BRIDGE INSPECTION AND MAINTENANCE	
A1	Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.
A2	Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?
A3	Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a damaged area with respect to: <ul style="list-style-type: none"> • Type of damage • Extent of damage • Criticality of damage and likely consequences • Likely cause of damage • Required actions to be taken
A4	Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?
QUESTIONS TO RAILROAD INSPECTION AND MAINTENANCE	
B1	Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.
B2	Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to: <ul style="list-style-type: none"> • Remove shavings and objects. • Melt problematic ice. • Lubricate switches.
B3	Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to): <ul style="list-style-type: none"> • Robustness to harsh weather/operating conditions. • Self-sufficiency, i.e. operation with a minimal of human attendance. • Ability to operate inside tunnels.
B4	Do you have any other relevant ideas or comments related to this topic?

QUESTIONS TO AIRPORT INSPECTION AND SURVEILLANCE	
C1	Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.
C2	Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports). And/Or do you have (planned) products or services that can help remove identified foreign objects?
C3	Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities? Interesting aspects includes (but is not limited to): <ul style="list-style-type: none"> • Robustness to harsh weather/operating conditions. • Self-sufficiency, i.e. ability to operate at (partially) unmanned airports.
C4	Do you have any other relevant ideas or comments related to this topic?
QUESTIONS TO OFFSHORE INSPECTION AND MAINTENANCE	
D1	Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.
D2	<ul style="list-style-type: none"> • Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to): • Blast cleaning systems • Paint/coating application systems • Underwater inspection • Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. • Other technology to eliminate/reduce the need for human access.
D3	Does your company offer or plan to offer ATEX certified equipment?
D4	Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)
D5	Do you have any other relevant ideas or comments related to this topic?

The responses that were received (note that not all companies provided responses) are included in Appendix A in alphabetical order. A summary per Support Category is provided in the following sections. Note that the summary is based on input received from the RINVE member companies and may not always indicate important details like the degree of autonomy involved or system limitations. The main purpose of the summary is to serve as inspiration for future collaboration between relevant end users and suppliers. Finally, note that known efforts or enabling technologies that were not specifically mentioned in the questionnaires have also been included, but that no complete industry review has been performed as part of this work.

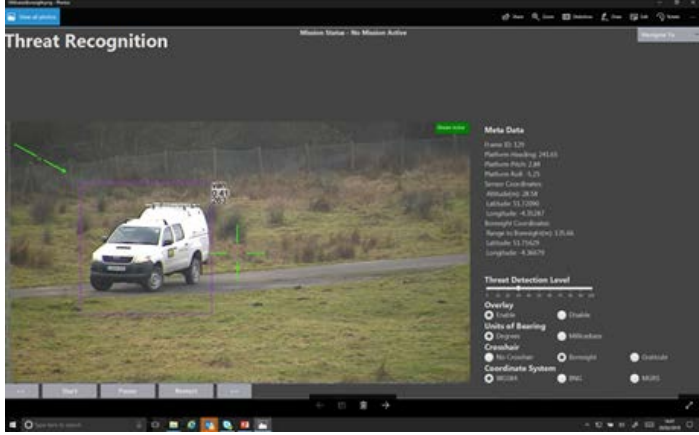
3.1.1 Status and Developments in Inspection, Maintenance and Repair Services

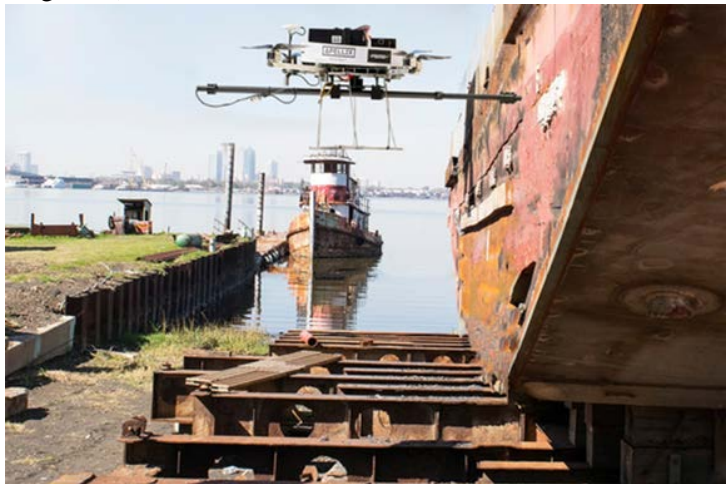
Over the past 10 years, the primary focus of the IM robotics industry has been on the development of tools to support robotic inspection and surveillance activities, but there is now a great push to use the new technologies also towards more demanding maintenance and repair tasks.

Today, there are very few automated painting/coating solutions suited for large industrial structures available commercially. The application of paint/coatings of high-quality is a complex operation where factors such as the paint texture and thickness, the surface (to be painted) texture, the application pressure, temperature and the visual evaluation of the paint that has been applied in order to make adjustments are important.

Table 4: Inspection, Maintenance and Repair Services Status

Functionality	Key Effort or Technology	Description
Autonomous Inspection	Ground inspection	A wide selection of systems on the market. RINVE member KVS Technologies develops a line of Unmanned Ground Vehicles with the ability to integrate a wide range of sensors.
	Aerial inspection	A wide selection of systems on the market. Several RINVE members offer solutions for aerial inspection, including Sevendof, Nordic Unmanned, Oceaneering, Maritime Robotics and AERSEA.
	Subsea inspection	A wide selection of systems on the market. RINVE member Maritime Robotics develops the mini Unmanned Surface Vehicle (USV) system OTTER that is suited for underwater inspection. A sidescan sonar can be used for structural integrity inspection and it can also be equipped with camera systems for subsurface visual inspection. RINVE member Oceaneering offers AUV and miniature subsea ROV technology. RINVE member AERSEA offers underwater ROVs and they are developing solutions for automated inspections under water.
	Automatic classification of damages	RINVE member Nordic Unmanned reports that they are working together with Lockheed Martin on using edge processing and software with auto detection to identify and classify damages during UAV flight.
	Smart surveillance technologies	RINVE member Nordic Unmanned reports that the Camflight FX8 drones are developed specifically for area inspections and surveillance, and that they plan to deliver an integrated service for this application. Nordic Unmanned collaborates with Lockheed Martin on software to detect and classify humans, cars, number plats, drones, changes in fences and tarmac and other relevant tasks.

		 <p style="text-align: center;">Surveillance Solutions. Credit: Nordic Unmanned</p>
	Small foreign object detection	Several RINVE members (Nordic Unmanned, Sevendof) reports success detecting very small objects using UAV LiDAR technology. Also, RINVE member Aersea is developing tools for object detection.
Autonomous surface treatments	Blasting	<p>The mobile blast cleaning robot developed for bridges by SABRE Autonomous Solutions shown in Figure 2, is also advertised for use in marine confined spaces such as for ballast and storage tanks and pressure vessels.</p> <p>RINVE member Surface Dynamics has remote controlled robots that have performed blast-cleaning commercially (particularly ballast tanks), and report to be working towards making the systems autonomous and applicable for more types of structures.</p> <p>RINVE member Oceaneering reports being in a development phase when it comes to this technology.</p>
	Cleaning/washing	<p>RINVE member Surface Dynamics has developed and tested remote controlled robots that have performed pre-washing commercially (particularly ballast tanks), and report to be working towards making the systems autonomous and applicable for more types of structures.</p> <p>RINVE member Oceaneering reports being in a development phase when it comes to this technology</p>
	Suitable paint/coatings	Develop paint/coatings that are better suited for automatic application and allows easy inspection of condition.
	Automatic application of paint/coatings	<p>Rather than leaving all the painting/coating challenges for the robotic system/vehicle targeted to apply the paint, it makes sense to develop a standardized paint application system that can be carried onboard any qualified robotic system/vehicle. Such a smart paint application system would be designed to optimize the relevant paint parameters (chemical mixture, thickness, application pressure etc) for a particular work surface.</p> <p>RINVE member PPG reported that they are currently working with Kongsberg Ferrotech, Petronas, Technip FMC and others on developing automated solutions for application.</p>

		RINVE member Surface Dynamics has remote controlled robots that have performed inspection, pre-cleaning and blast-cleaning commercially, and reports to be working towards making the systems autonomous and adding painting capability.
	Umbilical system for UAVs for substance application	The American company Appelix is working on developing a drone platform for cleaning and painting industrial surfaces called the Worker Bee™ ¹¹ . Their idea is to use ground-based power and material which is transferred through a patented umbilical system.
	Underwater treatments	There are underwater paints on the market ¹⁰ that could potentially support the development of an automated underwater painting/coating robot.
Maintenance and repair	Foreign object removal	RINVE member Nordic Unmanned states that they have developed a concept called STORK that allows collection of objects up to 6 kg that could potentially be adopted to remove foreign objects. RINVE member Sevendof states that they may be able to develop a custom solution capable of foreign object removal given end user interest and more detailed requirements.
	Dry film thickness measurement	The Smart Bee™, is a Non-Destructive Testing (NDT) UAV developed by Apellix with an attached Dry Film-Thickness (DFT) probe designed to touch the surface up to 100 m AGL ¹¹ , was named a recipient of a 2017 Corrosion Innovation of the Year Award (presented by <i>Materials Performance</i> magazine) ¹² . 
	Ultrasonic Testing to measure wall thickness	Apellix advertises a similar system as described under dry film thickness measurement, but with ultrasonic test probe attached instead of the DFT robe ¹¹ .

¹⁰ <http://www.unc-int.com/services/paint-and-adhesives-application-underwater/>

¹¹ <http://www.apellix.com/>


¹² <http://www.materialsperformance.com/articles/coating-linings/2017/08/drone-shows-promise-in-measuring-coating-thickness>



	Lubrication	RINVE member Nordic Unmanned reports that they have demonstrated a UAV-based autonomous spray lubrication solution to Bane NOR. RINVE member AERSEA is currently working on an automated solution for spraying of lubricants and ice phobic coating.
	Ice removal	RINVE member AERSEA offers anti-ice solutions for steel.

3.1.2 Status and Developments in Drones and Drone Technologies

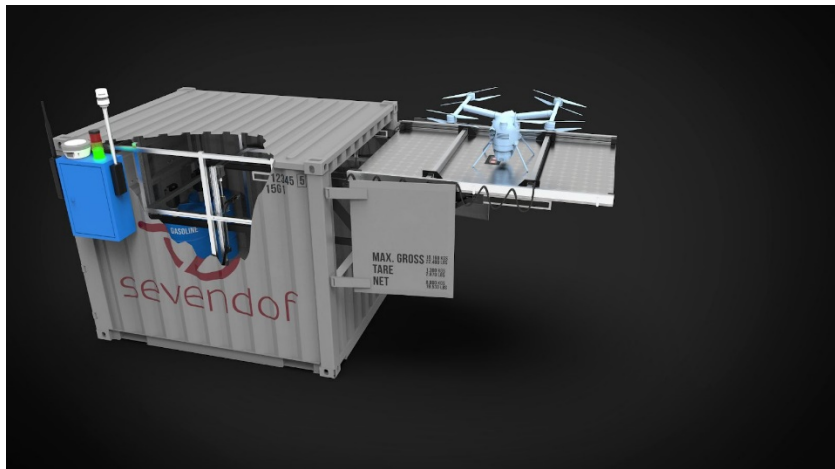
Drones have great potential to transform the way several industries perform their dirty, dull, dangerous and hard-to-access work. However, the success of the solutions depends on improving the reliability and durability performance of components and systems related to engine, propulsion and batteries, and also on the introduction of high precision navigation. The use of UAVs additionally faces critical mission restrictions due to small payload capability, low endurance and sensitivity to winds and harsh environments. Also, autonomous resident drones at unmanned facilities mean tougher requirements on high reliability and low frequency service/maintenance.



Table 5: Drone and Drone Technologies Status

Functionality	Key Effort or Technology	Description
UAV Payload capability	Modular payloads	<p>It is becoming increasingly common to develop modular payloads for UAVs that allows the same UAVs to be easily adopted to different tasks. Chinese MMC's "Plug-and-play" mount connector allows the selection of a wide variety of payloads simply by plugging them in.</p>  <p>MMC "Plug-and-play" Solution for Versatile UAS. Credit: MMC.</p>
	Smaller and lighter hardware	The cost and availability of smaller and lighter hardware is the key factor that allows UAS to be outfitted with increasingly sophisticated equipment and solutions.

	Heavy-duty drones	Norwegian Griff Aviation produces large all-electric UAVs that can transport a 150kg payload for 20 minutes and lift a maximum load of 200kg ¹³ .
	Lighting	<p>RINVE member Luminell offers professional drone lights that can be used to light up industrial structures at after dark (effectively expanding the operating time), in a tunnel or similar and also to eliminate shadows for better video/image quality during daylight hours.</p> <p>Luminell also brings up the idea of scaring birds/wildlife away from airports with use of drone lights. The company has also considered developing underwater lights for inspection.</p>   <p style="text-align: center;">Luminell Drone Lights. Credit: Luminell</p>
Navigation and Guidance	Collision avoidance	The ability to detect and avoid surrounding structure and obstacles is an essential capability in order for a drone to operate autonomously. The quality and capability of the collision avoidance function depends on the "smarts" built into the software navigation and control algorithms, but also depends heavily on the quality of the navigation sensors. Selected commercial drones are currently being delivered with systems for collision avoidance, but there are still limitations regarding which types of environment features that the collision avoidance systems can detect and handle.
	LiDAR	The quality of small LiDAR sensors has greatly improved in the past few years, offering better tools for navigation and object identification.
	ADS-B	ADS-B is an electronic identification system in which an aircraft determines its position via satellite navigation and periodically broadcasts it to allow tracking. ADS-B provides air-traffic awareness and should be used as an input into the collision avoidance

¹³<http://griffaviation.com/>

		<p>algorithms. Furthermore, it is expected to be required UAS equipment within a few years.</p> <p>RINVE member Sevendof report that they will operate using ADS-B transponders on all drones for added safety.</p>
	GPS degraded environments	<p>Many industrial structures will have areas with reduced or zero GPS coverage, thus require the UAS to have the ability to navigate without GPS for either shorter or indefinite time periods.</p> <p>RINVE member AERSEA reports that they are developing a drone/inspection tool for use where GPS is not available. The drone is targeted for inspections inside tanks and vessels.</p>
Autonomy	Drone "garages"/ ground stations	<p>The popular idea of a resident UAS to serve as the watchdog and ground keeper of a facility, requires a dedicated location where the UAV can be safely stowed away and charged between missions.</p> <p>RINVE member Sevendof plans to build and operate a network of ground stations housing long-range drones (less than 30 stations to cover all of mainland Norway). The drones will be autonomous, and the payload interface will allow custom payloads for different types of missions. Plans include to offer "drones-as-a-service" with inspection and /or maintenance services can be ordered through a web-interface.</p> <div data-bbox="598 987 1436 1453" data-label="Image">  </div> <p style="text-align: center;">Sevendof Automated Drone Station, Credit: Sevendof</p> <p>Another RINVE member, Nordic Unmanned, reports that they are developing a resident drone solution to be stationed at a facility with the ability to be activated by sensors or by remotely located operators. The first beta version is funded by Statnett and will be fully operational by the first quarter of 2019. RINVE member KVS Technologies develops the actual drone hangar for the Statnett project, which they state is capable of handling large snow depths of up to two meters and includes systems that enable operations in harsh environments, including moist and windy conditions. It also includes automated charging solutions for multi domain robotics.</p>
UAV Endurance	More efficient motors	<p>RINVE member Alva Motor Solutions develops low-weight, high-efficiency electric motors and generators for medium to large UAVs and airplanes. By reducing propulsion system weight, UAVs will gain longer flight-time and higher payload capacity.</p>

	<p>Increase battery duration</p>	<p>Current battery technology limits total flight time of most rotorcraft UAVs to about 30 minutes. There is a high likelihood that even more effective (i.e. higher energy-to-weight ratio) Lithium-based batteries will become available in the next few years, driven forward by high demands from other industries, such as the automotive and the consumer electronics industries.</p>
	<p>Adopt fuel cell technology</p>	<p>Chinese MMC has developed a drone, the HyDrone 1550, that is powered by a hydrogen fuel cell and can reportedly fly for more than three hours¹⁴. Intelligent-Energy develops fuel cells that are adoptable to most UAVs that are claimed to increase UAV flight times up to three times of what they can achieve using normal batteries¹⁵.</p>  <p>DJI Matrice 100 Powered by Intelligent Energy's Fuel Cell. Credit: BBC</p>
	<p>Tethered UAVs</p>	<p>Several UAV manufacturers offer an option of a tethered UAV capable of transmitting high definition video, power and control indefinitely. The T1 tether system by Chinese UAV manufacturer MMC is a universal system that can be used in combination with a wide selection of UAVs¹⁶.</p>  <p>T1 tether system by MMC for limitless flight times. Credit: MMC</p>
<p>UAV Safety and Hardware Survivability</p>	<p>ATEX</p>	<p>LE 4-8X Dual ATEX drone from French company Xamen Technologies has been awarded an ATEX Zone 2 certificate, i.e. it can be used in areas where hazardous gas or vapours are present on an occasional basis.</p>

¹⁴ <http://www.mmcuav.com/drones/>

¹⁵ <https://dronelife.com/2017/09/20/hydrogen-fuel-cells-drones-intelligent-energy/>

¹⁶ <http://www.mmcuav.com/drones/t1-tether-system/>

		<p>RINVE member Nordic Unmanned expresses interest in developing an ATEX certified UAV if a client funds the development.</p> <p>RINVE member KVS Technologies reports that their line of Unmanned Ground Vehicles can be delivered ATEX certified.</p> <p>RINVE member AERSEA reports that they are currently developing an ATEX Zone 1 drone for inspection purposes, and that they can provide inspections in ATEX Zone 2 areas today.</p> <p>RINVE member Luminell offers ATEX / IECEX certified floodlights and have the competence to also develop ATEX / IECEX certified drone lights.</p>
	Parachute system	<p>Several UAVs incorporate a parachute for safety and recoverability reasons. ParaZero¹⁷ develops the SafeAir™, an automatic parachute system that is triggered using independent sensors, will shut down the UAV engines, alert people on the ground with lights and sound and will deploy in fractions of a second for low altitude performance. The system can supposedly be fitted to most UAVs.</p>
	Anti-ice, De-icing	<p>Ice forming on wings, control surfaces and body of the UAV degrades the performance (reduces lift, adds drag) and can eventually cause the UAV to crash. Particularly for offshore and winter emergency/on-demand operations it may be necessary to add systems to detect and/or remove ice from (parts of) the UAV structure.</p>
	Waterproofness/ IP rating	<p>The first waterproof UAV systems are available already. British QUADH2O have specialized in waterproof multicopters, and their latest model, the HexH2O Pro v2, has a sealed waterproof body and is designed to land on the water without sinking¹⁸.</p> <p>RINVE member Nordic Unmanned are reports that they are currently finishing development of the Camflight FX8 drone to achieve an IP 53 rating with wind allowance up to 20 m/s.</p>

3.1.3 Status and Developments in Automation, Digitalization and Safety Solutions


Even if a UAS itself could be designed to operate autonomously, the UAS end users need solutions that are able to process the data "autonomously" and output results consisting of "high-level" decisions such as damage classifications, required maintenance actions and timelines. Candidate tools/techniques to transform the data collected by the platforms into high-level decisions includes "Big Data" analytics and artificial intelligence.

Table 6: Automation, Digitalization and Safety Status

Functionality	Key Effort or Technology	Description
Services	Drone network / Fleet operations	RINVE member Nordic Unmanned reports that they are working with Lockheed Martin on developing a software solution that would allow one operator to control multiple self-sufficient drones on remote locations on the same time.

¹⁷ <https://parazero.com/>

¹⁸ <https://www.quadh2o.com/hexh2o/hexh2o-pro-v2-ready-to-fly/>

		 <p style="text-align: center;">HMI Development. Credit: Nordic Unmanned</p> <p>RINVE member KVS Technologies reports that they are developing a modular integrated control system solution called Yggdrasil to enable remote operations of multiple UAVs and/or robots from different domains.</p>
Automatic data processing	Automatic reporting and maintenance planning	RINVE member Oceaneering reports that they have smart solutions for reporting and for using the data to improve/update the maintenance plan. The data can be transferred to other databases. RINVE member Aersea is developing a module for most off-the-shelf drone solutions and accompanying tools for planning, in order to speed up the inspections and to generate better information to support decision making. Aersea is particularly targeting automatic inspection of bridges and is looking into how to implement existing data from Brutus into their module.
	Mission-specific data presentation	Need to present the right data with the appropriate level of detail in an intuitive and easy to grasp fashion. The most relevant data may change over the course of a mission.
Fault detection and handling	Electrical circuit monitoring	RINVE member Oceaneering offers the CableGuardian product, which is designed to provide live insulation and conductor monitoring and generates alarms when faults appear. It monitors for open circuits, short circuit and low insulation resistance faults. Enables compliance with the requirements of Network Rail Standard NR/L2/SIGELP/27725.
	Corrosion monitoring	RINVE member Oceaneering reports having extremely robust equipment for monitoring corrosion.
Safety Management	Lifecycle requirements	RINVE member Oceaneering Asset Integrity offer Integrity Management, including strategy development, design review, gap analysis, integrity review, baseline, mitigation plan (including inspection plan), planning and review.

3.2 Key Opportunities for Automation/Robotics in Inspection and Maintenance

By considering the status and developments summarized in Section 3.1 up against the end user needs described in Section 2, a few areas that may be promising to explore further with other RINVE members have been summarized in Table 7.

Table 7: Summary of Opportunities for New Activities tied to IM in Automation and Robotics

END USER SECTOR	DESCRIPTION OF OPPORTUNITY
<p>ALL SECTORS</p>	<p>Automate the Analysis of Inspection Data For the automatic inspection to be truly useful, the output generated should not be a large dataset that requires human interpretation, but rather be high-level results that includes degree and extent of a damage, type of damage, cause of damage, consequence of damage and that also concludes on required actions/follow-up. Some enhancements to the inspection tools may be required in order to make reliable classifications, such as the possibility of measuring the thickness of paint/coatings by touching the relevant place with a probe.</p>
<p>Bridge IM</p>	<p>Develop a UAS Service Network Concept The high frequency of bridge inspection within certain areas warrants consideration of a concept where a small number of autonomous drones, a drone network, can serve as inspectors to a large number of bridges within reach of the drone network. The network may consist of several (preferably autonomous) base stations or drone garages where the drones can be stored, charged and can upload/download data. The drone network should be planned such that the drones avoid flight over densely populated areas and roads. Flying over rivers etc, may be a good option. Also, there should be redundancies in the system such that each bridge can be reached from more than one base station. The drone network should be monitored by a manned control centre.</p> <p>Improve the Robotic Maintenance Capability It is of particular interest to develop robotic tools suited to blast and paint/coat bridges without having to put up scaffolding and without impacting the traffic on the bridge.</p>
<p>Railroad IM</p>	<p>Develop a UAS Service Network Concept Similar to what is suggested for Bridge IM. In this case, the flight paths could follow the railroad tracks.</p> <p>Develop Automatic Foreign Object Detection and Removal Solution The ability to automatically detect and remove hazardous foreign objects/debris/shavings (possibly also ice) away from the tracks and switches. This is preferably done using a UAS to avoid disrupting the train traffic.</p> <p>Improve the Robotic Maintenance Capability It is of particular interest to develop robotic tools for lubrication of switches. UAS technology is most relevant to avoid disrupting the train traffic.</p>
<p>Airport IM</p>	<p>Develop a UAS "Grounds Keeper" Concept As Avinor is at the forefront in the world in the development of the remote towers concept, this offers a good opportunity for the Norwegian technology suppliers to enter into a collaboration to develop a robust UAS system specifically suited as a resident "grounds keeper" at this type of facility but also for other small airports that requires cost-effective solutions. Tasks should include inspection of runway and other critical structure, removal of small objects on the runway and scaring off birds and other wildlife. A "robot team" that involves both UAS and ground robots could relieve many of the inspection tasks which are carried out manually today. The robots will need a ground station or drone garage similar to what is described under Bridge IM Drone Service Network Concept.</p> <p>Develop Automatic Foreign Object Detection and Removal Solution</p>

	<p>Similar to what is suggested for Railroad IM, where the primary objective would be to detect and remove small objects from the runway. Some type of wheeled robot may be advantageous in case larger items need to be removed.</p>
	<p>Develop Concepts for Automatic Area Surveillance and Threat Mitigation Safe airport operations depend on the ability to keep undesirable vehicles/persons/animals away from the premises. The ability to automatically detect, classify and deter undesirable activities will help to provide the situational awareness and control that is desired, particularly in the remote towers concept. For instance, UAS have been used successfully to mimic predator birds to help scare birds away from the vicinity of the airport.</p>
<p>Offshore IM</p>	<p>Develop a UAS and UUV "Grounds Keeper" Concept Similar to what is suggested for Airport IM, however, UAS would be developed primarily for use at unmanned offshore facilities and will likely need to be ATEX certified.</p>
	<p>Improve the Robotic Maintenance Capability It is of particular interest to develop robotic tools for blasting and painting/coating offshore structures without having to put up scaffolding and also to develop automated solutions for performing inspection underneath insulation or equipment without having to remove it.</p>
	<p>Develop ATEX Approved Robots and Automatic Solutions For a robot or an automated solution to be able to operate in most areas of interest onboard a petroleum facility, the equipment has to be at least ATEX 1 certified.</p>

A Completed Supplier Surveys

The completed surveys from the following list of companies are included in alphabetic order:

- Aersea
- Alva Motor Solutions
- KVS Technologies
- Luminell
- Maritime Robotics
- Nordic Unmanned
- Norsk Regnesentral
- Oceaneering
- Sevendof

Questions to Bridge Inspection and Maintenance with responses from Aersea

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes, we are currently developing a faster and safer method for data acquisition for bridge inspections. Our module and tools for planning will make the inspections faster and give a better result for decision making.</p>
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>Yes, the module we are developing can be implemented in most off-the-shelf solutions when it comes to drones. This will make it much faster, cheaper and safe to conduct repeated and frequent inspections.</p>
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a damaged area with respect to:</p> <ul style="list-style-type: none"> - Type of damage - Extent of damage - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	<p>Yes, our tools and module can detect and be used for “automatic” inspection of bridges and infra structure in general. It can detect typical:</p> <p>Type of damage Extent of damage</p> <p>This can be used for considering cause of damage and used for better decisions for actions to be taken.</p>
<p>A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?</p>	<p>Yes, we are looking into how to implement existing data from Brutus into our module.</p>
<p>A5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>-</p>

Questions to Railroad Inspection and Maintenance with responses from Aersea

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes, our company is looking into developing tools for autonomous inspection of railroad tracks.</p>
<p>B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to:</p> <ul style="list-style-type: none"> - Remove shavings and objects. - Melt problematic ice. - Lubricate switches. 	<p>Yes, our company can already offer anti-ice solutions for steel. We are currently working on an automated solution for spraying of lubricants and ice phobic coating.</p>
<p>B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. operation with a minimal of human attendance. - Ability to operate inside tunnels. 	<p>Yes, our purpose made tool will be feasible solution for operating with less human interaction, inside of tunnels, in harsh weather and so.</p>
<p>B4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>-</p>

Questions to Airport Inspection and Surveillance with responses from Aersea

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.</p>	<p>No, not at the moment.</p>
<p>C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports).</p> <p>And/Or do you have (planned) products or services that can help remove identified foreign objects?</p>	<p>Yes, we are developing tools for object detection. It is not purpose made for runway inspections but can easily be used for the same purpose.</p>
<p>C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. ability to operate at (partially) unmanned airports. 	<p>Yes, our company are developing tools purpose made for other similar jobs. It can be used for this purpose.</p>
<p>C4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>-</p>

Questions to Offshore Inspection and Maintenance with responses from Aersea

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes, our company are currently developing a ATEX Zone 1 drone for inspection purposes.</p>
<p>D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to):</p> <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	<p>Yes, our company are developing solutions for automated inspections under water. Light tools for use on light ROVs. We have drones capable to take pictures up to 30X zoom and it is possible to also connect different kind of sensors.</p>
<p>D3. Does your company offer or plan to offer ATEX certified equipment?</p>	<p>Yes, our company are currently developing an ATEX Zone 1 approved drone. We can provide inspections in ATEX Zone 2 areas today.</p>
<p>D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)</p>	<p>Yes, our company is developing a drone/inspection tool in use where there is no GPS signal. Specially made for inside inspections of tanks and vessels.</p>
<p>D5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>-</p>

Questions to Bridge Inspection and Maintenance with responses from Alva Motor Solutions

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Alva Motor Solutions (Alva Industries AS) develops low-weight, high-efficiency electric motors and generators for medium to large UAVs and airplanes.</p> <p>By reducing propulsion system weight, UAVs will gain longer flight-time and higher payload capacity.</p> <p>Alva is currently entering a €2M, 2-year project with two European partners to develop an integrated motor-duct-propeller (MDP) solution for medium to high thrust applications. Norwegian partners or potential customers are welcome to be involved.</p>
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>No</p>
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a damaged area with respect to:</p> <ul style="list-style-type: none"> - Type of damage - Extent of damage - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	<p>No</p>
<p>A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?</p>	<p>No</p>
<p>A5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>No</p>

Questions to Railroad Inspection and Maintenance with responses from Alva Motor Solutions

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Same as above.</p>
<p>B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to:</p> <ul style="list-style-type: none"> - Remove shavings and objects. - Melt problematic ice. - Lubricate switches. - 	<p>No</p>
<p>B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. operation with a minimal of human attendance. - Ability to operate inside tunnels. 	<p>No</p>
<p>B4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>No</p>

Questions to Airport Inspection and Surveillance with Responses from Alva Motor Solutions

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.	Same as above
C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports). And/Or do you have (planned) products or services that can help remove identified foreign objects?	No
C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities? Interesting aspects includes (but is not limited to): <ul style="list-style-type: none">- Robustness to harsh weather/operating conditions.- Self-sufficiency, i.e. ability to operate at (partially) unmanned airports.	No
C4. Do you have any other relevant ideas or comments related to this topic?	No

Questions to Offshore Inspection and Maintenance with Responses from Alva Motor Solutions

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.	Same as above
D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to): <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	No
D3. Does your company offer or plan to offer ATEX certified equipment?	No
D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)	No
D5. Do you have any other relevant ideas or comments related to this topic?	No

Questions to Bridge Inspection and Maintenance with KVS Technologies Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>No relevant products</p>
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>No relevant products</p>
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a damaged area with respect to:</p> <ul style="list-style-type: none"> - Type of damage - Extent of damage - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	<p>No relevant products</p>
<p>A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?</p>	<p>No relevant products</p>
<p>A5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>No relevant products</p>

Questions to Railroad Inspection and Maintenance with KVS Technologies Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>KVS Technologies is currently leading Norway’s largest UAV integration project where the company provides system integration and the control system enabling Remote Operations for multiple UAVs and robotics of different domains.</p> <p>http://www.statnett.no/Media/Nyheter/Nyhetsarkiv-2018/Droner-skal-passe-pa-Statnetts-stromledninger/</p> <p>The system have several use cases applicable for railroad inspections.</p>
<p>B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to:</p> <ul style="list-style-type: none"> - Remove shavings and objects. - Melt problematic ice. - Lubricate switches. 	<p>The Yggdrasil Robotic Control System is developed for being able to quickly integrate</p>
<p>B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. operation with a minimal of human attendance. - Ability to operate inside tunnels. 	<p>Our UAV hangar system developed for our project with Statnett is capable of handling large snow depths of up to two meters. The hangar has systems integrated that enable operations in harsh environments, including high moist and windy conditions. The system is adaptable to incorporate a wide range of UAV systems, and provides optional rapid charging technology for sustained operations during emergency response.</p>
<p>B4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>No other relevant comments.</p>

Questions to Airport Inspection and Surveillance with KVS Technologies Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.</p>	<p>KVS Technologies is working on technology for automated remote inspections of features on Airports.</p> <p>This include autonomous and semi-autonomous systems able to operate in harsh Norwegian Weather Conditions by using robust and well proven technology.</p>
<p>C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports).</p> <p>And/Or do you have (planned) products or services that can help remove identified foreign objects?</p>	<p>No relevant products</p>
<p>C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. ability to operate at (partially) unmanned airports. 	<p>Our systems that today are developed for automated inspections and emergency response for Statnett, are suited for modifications to be able to operate in airport areas.</p> <p>This includes automated charging solutions for multi domain robotics, in addition to harsh weather operational capacity.</p>
<p>C4. Do you have any other relevant ideas or comments related to this topic?</p>	



Questions to Offshore Inspection and Maintenance with KVS Technologies Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Our modular Yggdrasil Control System for multi domain robotics is capable of controlling a wide range of robotic solutions. Combining this with the ability to operate our harsh weather hangar in the same system, makes us your ideal integration partner integration of mobile robotics into your value chain.</p> <p>We are always interested in discussion for integration of new robotic systems into the Yggdrasil Control system.</p>
<p>D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to):</p> <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	
<p>D3. Does your company offer or plan to offer ATEX certified equipment?</p>	<p>Our line of Unmanned Ground Vehicles can be delivered ATEX certified. In combination with the ability to integrate a wide range of sensors they are ideal for monitoring and establishing of Situational Awareness onboard Normally Unmanned Installation.</p>
<p>D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing,</p>	

Questions to Bridge Inspection and Maintenance with Luminell Responses




(Do not include confidential information. All contributions may be made public)


QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes, Luminell Drone Light offers professional drone lights that can be used for bridge inspection and maintenance.</p> <p>Here is more information about the products: https://luminell.com/products/drone-lights/</p> <p>Here is a video from bridge inspection https://luminell.com/products/drone-lights/dl-a-drone-light-module/#dl-a-videos</p> 
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>Yes, use of light will help performing inspections in a safe manner, even after dark.</p> 
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be</p>	<p>When using light, even during daytime, it will increase to the chance to take photo/video with good enough light to see the damage better.</p> <p>Under bridges there are often areas of shadow</p>

<p>used to classify a damaged area with respect to:</p> <ul style="list-style-type: none"> - Type of damage - Extent of damage - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	
<p>A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?</p>	<p>Do not have enough knowledge about Brutus to know. If pictures/videos are stored, lights might help the quality of the pictures</p>
<p>A5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>Our experience is that it is helpful to use light even during daytime due to shadows under bridges.</p>

Questions to Railroad Inspection and Maintenance with Luminell Responses


(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes, Luminell Drone Light offers professional drone lights that can be used for railroad inspection and maintenance.</p> <p>Here is more information about the products: https://luminell.com/products/drone-lights/</p> <p>Here is a video from bridge inspection https://luminell.com/products/drone-lights/dl-a-drone-light-module/#dl-a-videos</p> <div style="text-align: center;">   </div>
<p>B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to:</p> <ul style="list-style-type: none"> - Remove shavings and objects. - Melt problematic ice. - Lubricate switches. 	<p>Using light will expand the operating times, and could make inspection during dark hours possible. https://luminell.com/products/drone-lights/dl-c-drone-light-module/#dl-c-videos</p> <p>The DL C modules are very powerful and can illuminate larger areas.</p> <div style="text-align: center;">  </div>

<p>B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none">- Robustness to harsh weather/operating conditions.- Self-sufficiency, i.e. operation with a minimal of human attendance.- Ability to operate inside tunnels.	<p>Yes, using light will be very helpful here, also in tunnels where it is dark in general. The products are robust enough to be used in harsh weather / operating conditions.</p> <p>In the end of this video is a short clip from a tunnel</p> <p>https://luminell.com/products/drone-lights/dl-a-drone-light-module/#dl-a-videos</p>  <p>The image shows a long, dark tunnel with rough, rocky walls. In the foreground, the dark silhouette of a person stands with their back to the camera, looking down the tunnel. In the middle distance, a small drone with glowing lights is visible, flying towards the viewer. The tunnel is dimly lit, with some light reflecting off the wet-looking floor.</p>
<p>B4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>Light are very helpful for inspections</p>



Questions to Airport Inspection and Surveillance with Luminell Responses


(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.</p>	<p>Drone lights.</p> 
<p>C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports).</p> <p>And/Or do you have (planned) products or services that can help remove identified foreign objects?</p>	<p>Using light on drones will make it possible to illuminate the areas that is to be detected. And if there's a camera that works in daylight that can detect the objects, it can be a good combination.</p> <p>Maybe it is possible to remove objects like birds/animals using lights? The light modules can be deliver with both IR and UV light.</p>
<p>C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. ability to operate at (partially) unmanned airports. 	<p>Drone lights</p>
<p>C4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>The combination of light, either white, UV or IR with camera can be an interesting solution.</p>

Questions to Offshore Inspection and Maintenance with Luminell Responses


(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes, Luminell Drone Light offers professional drone lights that can be used for railroad inspection and maintenance.</p> <p>Here is more information about the products: https://luminell.com/products/drone-lights/</p> <p>Here is a video from bridge inspection https://luminell.com/products/drone-lights/dl-a-drone-light-module/#dl-a-videos</p> <div style="text-align: center;">  </div>
<p>D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to):</p> <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	<p>Light will definitely reduce the need for human access, since drones then can be used for inspection during all hours of the day.</p> <p>Luminell has also considered developing underwater lights for inspection.</p> <div style="text-align: center;">  </div>

<p>D3. Does your company offer or plan to offer ATEX certified equipment?</p>	<p>Yes. Luminell offers ATEX / IECEx certified floodlights and have the competence to also develop ATEX / IECEx certified drone lights.</p>
<p>D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)</p>	<p>Yes, light can be used for these purposes.</p> 
<p>D5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>We believe that light is a must have on a drone for offshore inspection and maintenance. There are structures onboard offshore installations that will cause shadows and darker areas also during daytime.</p> <p>Our light modules have several beam options, which makes it possible to illuminate objects even on longer distances.</p>

Questions to Bridge Inspection and Maintenance with Maritime Robotics Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Above surface: standard drone inspection with imagery, multispectral scans and LIDAR</p> <p>Below surface: Mini USV system OTTER with sidescan sonar for inspecting around the pillars on the sea floor, and integrity up to surface. Can also be equipped with camera systems for subsurface visual inspection</p> 
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>Does not offer at this time, but can be interested in setting up such a system based on current and future products and services.</p>
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a</p>	<p>Yes</p>

damaged area with respect to: <ul style="list-style-type: none"> - Type of damage - Extent of damage - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	
A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?	No
A5. Do you have any other relevant ideas or comments related to this topic?	

Questions to Railroad Inspection and Maintenance with **Maritime Robotics** Responses
(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.	Standard drone inspection with imagery, multispectral scans and LIDAR
B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to: <ul style="list-style-type: none"> - Remove shavings and objects. 	Yes

<ul style="list-style-type: none"> - Melt problematic ice. - Lubricate switches. 	
<p>B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. operation with a minimal of human attendance. - Ability to operate inside tunnels. 	Yes
<p>B4. Do you have any other relevant ideas or comments related to this topic?</p>	

Questions to Airport Inspection and Surveillance with **Maritime Robotics** Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.</p>	<p>Yes</p>
<p>C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports).</p> <p>And/Or do you have (planned) products or services that can help remove identified foreign objects?</p>	<p>Yes</p>
<p>C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. ability to operate at (partially) unmanned airports. 	<p>Yes</p>
<p>C4. Do you have any other relevant ideas or comments related to this topic?</p>	

Questions to Offshore Inspection and Maintenance with Maritime Robotics Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes</p>
<p>D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to):</p> <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	<p>Yes</p>
<p>D3. Does your company offer or plan to offer ATEX certified equipment?</p>	<p>Yes</p>
<p>D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)</p>	<p>Yes</p>
<p>D5. Do you have any other relevant ideas or comments related to this topic?</p>	

Questions to Bridge Inspection and Maintenance with Nordic Unmanned Responses

(Do not include confidential information. All contributions may be made public)

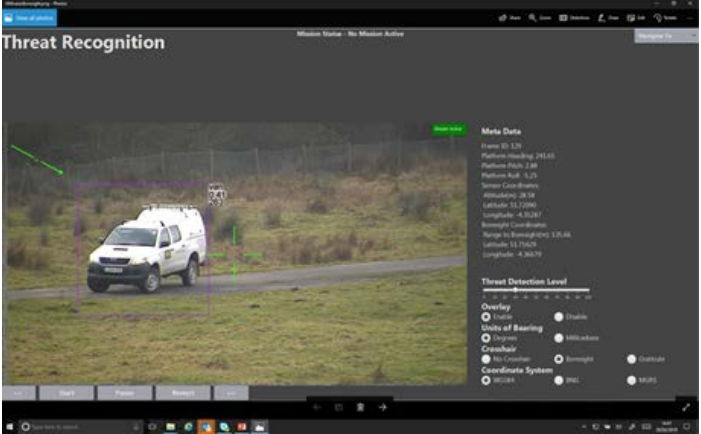


QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes. Drone inspection with optical, thermal and LiDAR sensor. Full pointcloud of the inspection report that gets translated into 3D model.</p>
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>Yes, we are developing a resident drone solution that will be stationed on asset and activated by sensors or remote located operators. First beta is funded by Statnett and will be fully operational ready Q1 2019</p>
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a damaged area with respect to:</p> <ul style="list-style-type: none"> - Type of damage - Extent of damage - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	<p>Yes, we are working together with Lockheed Martin on using edge processing and software with auto detection to identify and classify damages during flight.</p>
<p>A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?</p>	<p>NO</p>
<p>A5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>Sign framework contract that allows for development between supplier, end user and technology.</p>

Questions to Railroad Inspection and Maintenance with **Nordic Unmanned** Responses

(Do not include confidential information. All contributions may be made public)

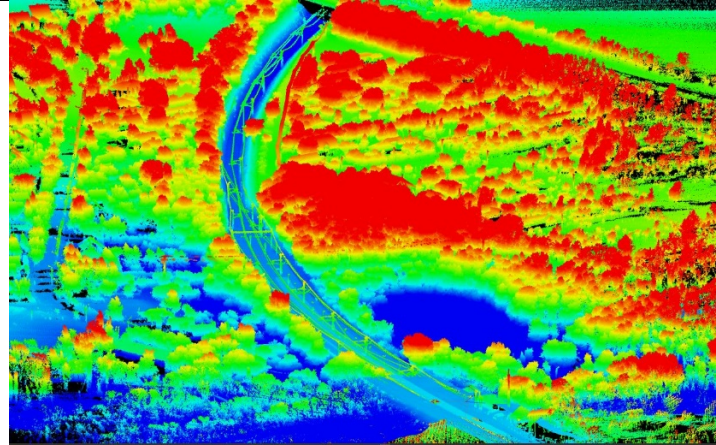
QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.	
B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to: <ul style="list-style-type: none">- Remove shavings and objects.- Melt problematic ice.- Lubricate switches.	
B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to): <ul style="list-style-type: none">- Robustness to harsh weather/operating conditions.- Self-sufficiency, i.e. operation with a minimal of human attendance.- Ability to operate inside tunnels.	
B4. Do you have any other relevant ideas or comments related to this topic?	

Questions to Airport Inspection and Surveillance with **Nordic Unmanned Responses**
(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.</p>	<p>Yes. Our Camflight FX8 drones are developed with restricted area inspections and surveillance in mind. We plan to deliver an integrated service of a resident drone with relevant software, sensors and applications for this solution. We are working with Lockheed Martin on including software that would detect and classify humans, cars, number plats, drones, changes in fences and tarmac and other relevant tasks.</p>   
<p>C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the</p>	<p>Yes. We are currently using LiDAR on drone for this purpose. The LiDAR detects down to 10-15 mm with near real-time processing. As the LiDAR uses laser and not pixel it does not require a minimum amount of light to get needed data, so the solution works 24/7 year round in all parts of Norway.</p>

runway? (The solutions should be affordable for small airports).

And/Or do you have (planned) products or services that can help remove identified foreign objects?



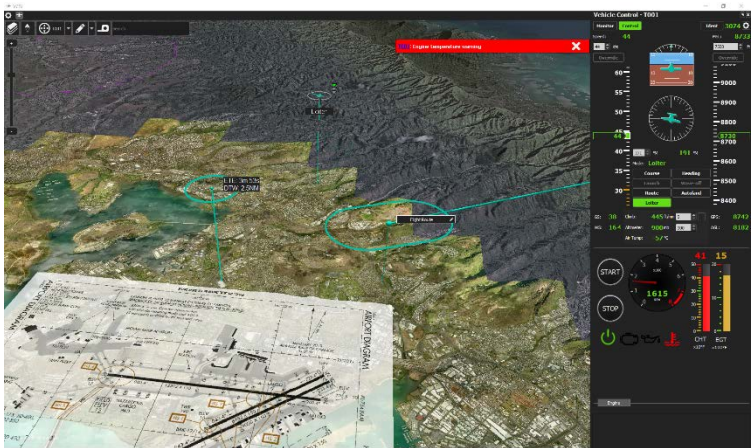
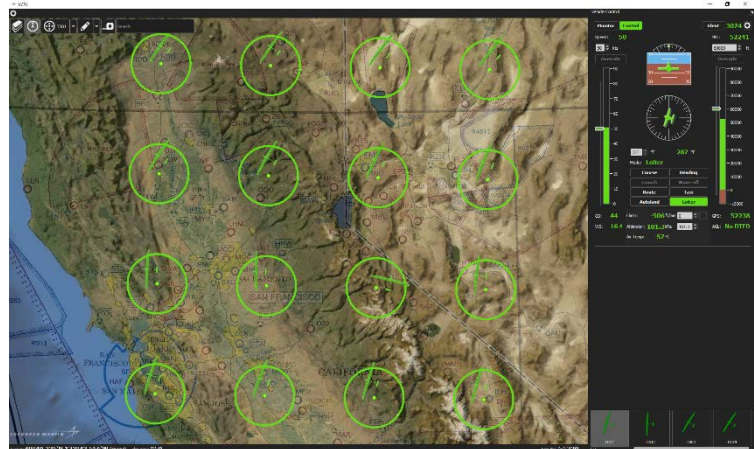
Funded by Innovasjon Norge we have done a study of Drone logistics, delivery and collection of upto 6 kg of weight. The concept is called STORK and could potentially be used to remove foreign objects.

C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities?

Interesting aspects includes (but is not limited to):

- Robustness to harsh weather/operating conditions.
- Self-sufficiency, i.e. ability to operate at (partially) unmanned airports.

Yes. We are doing airborne (drone) developing project related to this for both Bane NOR and Statnett. We are currently finishing a robustness development on our Camflight FX8 drone to get it up to a IP 53 rating with wind allowance up to 20 m/s. Together with Lockheed Martin we are locking into including software that would allow one operator to control multiple self-sufficient drones on remote locations on the same time.



<p>C4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>We suggest putting a feasibility study out on an RFQ as there are available technology on TRL 5-7 level.</p>
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Questions to Offshore Inspection and Maintenance with Nordic Unmanned Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes. Inspection with use of drone with optical and thermal camera. Digitalization of brownfield assets using drone and LiDAR sensor.</p>
<p>D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to):</p> <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	<p>Yes. We currently have developed low TRL level logistical solutions for our drone, pilot line polling solution, and autonomous spray lubrication solution demonstrated for BaneNOR.</p>
<p>D3. Does your company offer or plan to offer ATEX certified equipment?</p>	<p>We plan to offer if a client pays for the development.</p>
<p>D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)</p>	<p>Our drones are handling some of these issues, but further development will only happen when users are willing to share the cost of getting the drone to handling more of the challenging factors.</p>
<p>D5. Do you have any other relevant ideas or comments related to this topic?</p>	

Norsk Regnesentral (NR) is a foundation carrying out contract research and development projects in ICT and applied statistical modeling, including image analysis, machine learning and remote sensing. NR works with many different types of data, including images from airborne platforms (drones, unmanned planes, and satellites), multi- and hyperspectral images, synthetic aperture radar images, acoustic images (seismic, sonar, ultrasound) and data from various types of optical cameras. We have extensive knowledge in the fields of image analysis, machine learning and deep learning. Detection, segmentation, characterization and classification of images are central in many of these applications. Our focus is on developing new methodologies to solve specific problems for our customers.

Image analysis can in general provide automatic inspection for visible faults – such as cracks, missing paint, wearing damages, missing parts, or unwanted objects. It may also be used to detect faults that are only visible using other image modalities, such as IR-camera or ultrasound. The input images or video for this can be recorded from stationary cameras or cameras carried by a robot or drone. If the recordings are made on a regular basis, image analysis could be used to monitor how the state of equipment and assets change over time.

In relation to the other service providers in the RINVE-network we see NR contributing on the data analysis side. Potentially using data recorded from drones or other robotic solutions provided by other service providers.

Questions to Bridge Inspection and Maintenance with **Oceaneering** Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Oceaneering Asset Integrity offer today Integrity Management, this includes strategy development, design review, gap analysis, integrity review, baseline, mitigation plan, planning and review. Inspection is a part of the mitigation plan. We are approximately 250 employees in Norway working within this field.</p>
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>Yes indeed we do. But our understanding is that Statens Vegvesen are extremely conservative and prefer to work with the suppliers that they already know. And finally price is the only thing that matters.</p>
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a damaged area with respect to:</p> <ul style="list-style-type: none"> - Type of damage - Extent of damage - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	<p>Yes, but mainly based on using drones.</p>
<p>A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?</p>	<p>Yes, we have already smart solutions for reporting, and to use the data, to improve/update the actual maintenance plan. Data can be transferred to other databases.</p>

A5. Do you have any other relevant ideas or comments related to this topic?	
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Questions to Railroad Inspection and Maintenance with **Oceaneering** Responses
(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.	<p>Please find attached our datasheet on the CableGuardian product. This product is designed to monitor the electrical integrity of the trackside signalling power distribution system. It monitors for open circuit, short circuit and low insulation resistance faults.</p> <p>Key benefits are:</p> <ul style="list-style-type: none"> • Helps to avoid injury and reduce downtime through early fault detection and location • Analytics facilitate proactive, rather than reactive, maintenance • Enables faster and more accurate repair, minimising service outage • Permits a move from a frequency based inspection regime to one driven by actual asset condition and performance • Enables compliance with the requirements of Network Rail Standard NR/L2/SIGELP/27725 <p>An animation of the product can be viewed at the product webpage below:</p> <p>http://www.viperinnovations.com/products-and-services/cableguardian</p>
B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance	NO

<p>activities? Interesting functions includes (but is not limited to) the ability to:</p> <ul style="list-style-type: none"> - Remove shavings and objects. - Melt problematic ice. - Lubricate switches. 	
<p>B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. operation with a minimal of human attendance. - Ability to operate inside tunnels. 	NO
<p>B4. Do you have any other relevant ideas or comments related to this topic?</p>	NO

Questions to Airport Inspection and Surveillance with **Oceaneering** Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.</p>	<p>NO</p>
<p>C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports).</p> <p>And/Or do you have (planned) products or services that can help remove identified foreign objects?</p>	<p>NO</p>
<p>C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. ability to operate at (partially) unmanned airports. 	<p>NO</p>
<p>C4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>NO</p>

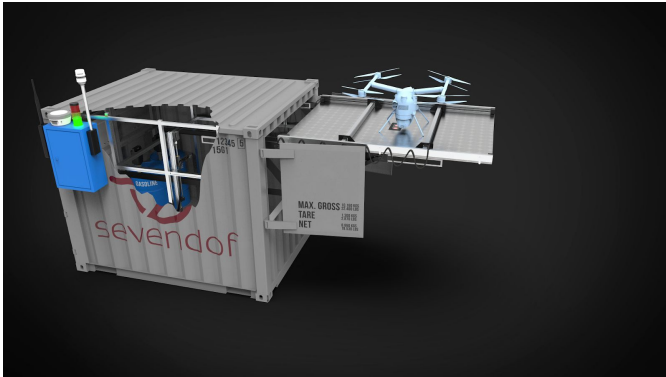

Questions to Offshore Inspection and Maintenance with **Oceaneering** Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Oceaneering Asset Integrity offer today Integrity Management, this includes strategy development, design review, gap analysis, integrity review, baseline, mitigation plan, planning and review. Inspection is a part of the mitigation plan. We are approximately 250 employees in Norway working within this field.</p>
<p>D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to):</p> <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	<p>As a Company, we are involved in all the mentioned tools and capabilities. Sometimes we develop and the tools our selves, and sometimes we have a partner. For the blasting and paint/coating we are in a development phase.</p>
<p>D3. Does your company offer or plan to offer ATEX certified equipment?</p>	<p>We do have some equipment that are ATEX certified.</p>
<p>D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)</p>	<p>Yes, we have equipment for monitoring corrosion, that are extremely robust.</p>
<p>D5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>NO</p>


Questions to Bridge Inspection and Maintenance with Sevendof Responses


(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>A1. Does your company offer or plan to offer products or services that may be of use in the field of Bridge Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes. Sevendof plans to build and operate a network of stations housing long-range drones for inspection usage. We target a minimum range of 200 km, enabling us to cover the entire Norwegian mainland with fewer than 30 stations. Our drones will be equipped with optical and LiDAR sensors capable of producing accurate 3D scans of bridges, and will be equipped with a payload interface enabling custom payloads which may enable certain types of maintenance or other inspection scans. Our drones will be operated automatically, enabling ordering of inspection missions both through a web interface as well as through our API. We hope to provide an attractive service cost to end-users through cost sharing, as our drones will also be used for other tasks such as mapping, surveillance, and search and rescue for different end-users.</p>  
<p>A2. Does your company offer or plan to offer products or services that may be a useful part in a solution to allow the weekly general inspections to be performed in a safe manner by use of automation/sensors/drones (i.e. no human presence on the bridge required)?</p>	<p>Yes. Our drone network will enable safe recurring inspections without human involvement. As our drones are stationed in automated drone stations, their entire mission can be carried out automatically. Local sensors and autonomy enable flights close to structures safely. Our system will make it possible to weekly capture data for different bridges.</p>
<p>A3. Does your company offer or plan to offer products or services that allows automation/robots/drones to be used to classify a damaged area with respect to:</p> <ul style="list-style-type: none"> - Type of damage - Extent of damage 	<p>Our focus is to offer domain agnostic data capture and not perform domain specific analysis. We prefer cooperating with another entity who performs domain specific analysis, either through off-line processing, or through running their application on our drone performing analysis during flight.</p>

<ul style="list-style-type: none"> - Criticality of damage and likely consequences - Likely cause of damage - Required actions to be taken 	
<p>A4. Does your company offer or plan to offer products or services that allows the data contained in Brutus to be used for added value purposes?</p>	<p>No.</p>
<p>A5. Do you have any other relevant ideas or comments related to this topic?</p>	<p>We believe recurring 3D-scans of bridges offer an excellent opportunity to track their state over time, especially as differences in 3D-models may be estimated and highlighted automatically without any domain knowledge.</p>

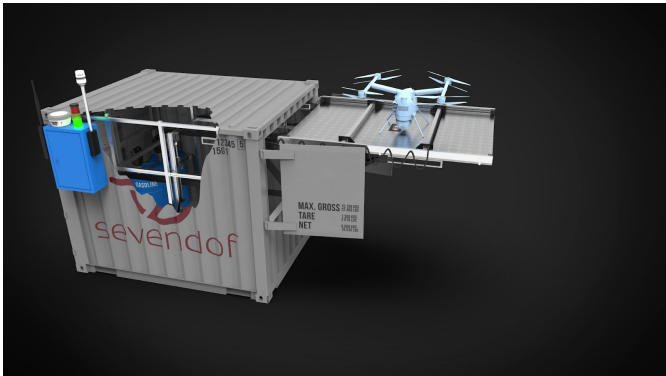

Questions to Railroad Inspection and Maintenance with Sevendof Responses
(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>B1. Does your company offer or plan to offer products or services that may be of use in the field of Railroad Inspection and Maintenance? If so, provide some details of shared interests.</p>	<p>Yes. Sevendof plans to build and operate a network of stations housing long-range drones for inspection usage. We target a minimum range of 200 km, enabling us to cover the entire Norwegian mainland with fewer than 30 stations. Our drones will be equipped with optical and LiDAR sensors capable of producing accurate 3D scans of railroads, and will be equipped with a payload interface enabling custom payloads which may enable certain types of maintenance or other inspection scans. Our drones will be operated automatically, enabling ordering of inspection missions both through a web interface as well as through our API. We hope to provide an attractive service cost to end-users through cost sharing, as our drones will also be used for other tasks such as mapping, surveillance, and search and rescue for different end-users.</p> 

	
<p>B2. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for railroad inspection and maintenance activities? Interesting functions includes (but is not limited to) the ability to:</p> <ul style="list-style-type: none"> - Remove shavings and objects. - Melt problematic ice. - Lubricate switches. 	<p>With our automatic payload swap system, we could store payloads for handling the melting of ice, and payloads for applying lubricant, within our automated drone stations. This would enable drones which normally are use for inspection to perform ice melting and lubricant application as routine tasks.</p> 
<p>B3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for Railroad Inspection and Maintenance activities? Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none"> - Robustness to harsh weather/operating conditions. - Self-sufficiency, i.e. operation with a minimal of human attendance. - Ability to operate inside tunnels. 	<p>Sevendof plans to offer drones as a service, enabling airborne drones to be automatically deployed both for inspection and maintenance activities from drone stations in the field. Our industrial drone system is built with rugged components and encapsulation, in order to handle a wide array of missions and enable long service intervals. It is designed to operate automatically, with no human support in the field, and will be capable of flying within tunnels.</p>
<p>B4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>In a mostly domain agnostic fashion, we should be able to automatically detect debris and the state of railroad components while flying over railroad tracks using a LiDAR sensor.</p>

Questions to Airport Inspection and Surveillance with Sevendof Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
<p>C1. Does your company offer or plan to offer products or services that may be of use in the field of Airport Inspection and Surveillance? If so, provide some details of shared interests.</p>	<p>Yes. Sevendof plans to build and operate a network of stations housing long-range drones for inspection usage. We target a minimum range of 200 km, enabling us to cover the entire Norwegian mainland with fewer than 30 stations. Our drones will be equipped with optical and LiDAR sensors suitable for airport inspection and surveillance, and will be equipped with a payload interface enabling custom payloads which may enable certain types of maintenance or other inspection scans. Our drones will be operated automatically, enabling ordering of inspection missions both through a web interface as well as through our API. We hope to provide an attractive service cost to end-users through cost sharing, as our drones will also be used for other tasks such as mapping and search and rescue for different end-users.</p>  
<p>C2. Does your company offer or plan to offer products or services that may help to enable automatic detection of foreign objects down to 2 cm length/diameter on the runway? (The solutions should be affordable for small airports).</p> <p>And/Or do you have (planned) products or services that can help remove identified foreign objects?</p>	<p>Yes, given drone flight with a LiDAR sensor such as the RIEGL miniVUX-1UAV, we should be able to detect objects down to 2 cm from a distance of 5 meters. http://products.rieglusa.com/item/all-categories-unmanned-scanners/minivux-1uav--airborne-laser-scanners/riegl-minivu-x-1uav Given more knowledge of the target domain, a custom payload capable of foreign object removal may be developed.</p>
<p>C3. Does your company offer or plan to offer products or services that may be useful in the development of a robotic (possibly airborne) system for airport inspection and maintenance activities?</p>	<p>Sevendof plans to offer drones as a service, enabling airborne drones to be automatically deployed both for inspection and maintenance activities from drone stations in the field. Our industrial drone system is built with rugged components and encapsulation, in order to handle a wide array of missions</p>

<p>Interesting aspects includes (but is not limited to):</p> <ul style="list-style-type: none">- Robustness to harsh weather/operating conditions.- Self-sufficiency, i.e. ability to operate at (partially) unmanned airports.	<p>and enable long service intervals. It is designed to operate automatically, with no human support in the field, as well as support interaction with airport personnel in order to provide full control of the operation.</p>
<p>C4. Do you have any other relevant ideas or comments related to this topic?</p>	<p>Sevendof will operate using ADS-B transponders on all drones for added safety.</p>

Questions to Offshore Inspection and Maintenance with Sevendof Responses

(Do not include confidential information. All contributions may be made public)

QUESTION	ANSWER/DISCUSSION (Include pictures where relevant!)
D1. Does your company offer or plan to offer products or services that may be of use in the field of Offshore Inspection and Maintenance? If so, provide some details of shared interests.	No.
<p>D2. Does your company offer or plan to offer products or services that may be of use in the development of maintenance tools suited for use by robotics (possibly airborne) systems? Interesting capabilities/tools includes (but is not limited to):</p> <ul style="list-style-type: none"> - Blast cleaning systems - Paint/coating application systems - Underwater inspection - Maintenance tool technology that is compact and light enough to fit onboard an unmanned aerial vehicle. - Other technology to eliminate/reduce the need for human access. 	
D3. Does your company offer or plan to offer ATEX certified equipment?	
D4. Does your company offer or plan to offer equipment/instruments that is particularly well suited to address problems caused by offshore environmental factors? (E.g. low-temperatures, rain/snow, icing, winds, saltspray, GPS challenged/denied areas.)	
D5. Do you have any other relevant ideas or comments related to this topic?	



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