Design considerations for mobile offshore Oil & Gas inspection robots

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ABSTRACT

Operations on offshore Oil & Gas platforms involve a high risk of accidents. Tasks have to be performed around the clock, in all kinds of weather. In order to increase safety, companies are obliged to perform inspections and regular maintenance controlled by governmental law. It's mainly repetitive tasks that cost companies hundreds of thousands of dollars each year. With continuous emerges in technology, the competition keeps getting tougher by deploying smart technology throughout the processes. This article explores the possible application of robots performing inspection and maintenance in large Oil & Gas platforms. As a result, features of such a robot is outlined. Furthermore, a discussion on how designers can use their skill set and experience with User-Centered design to shape the future of Oil & Gas solutions is performed.

KEYWORDS: Oil & Gas, Automation, Robot, Inspection and Maintenance.

1. INTRODUCTION

We are right now in the beginning of the Industrial Internet of Things (IIOT). With a rapid development in computer power and cloud services, industries like Oil & Gas are facing great potential to gain valuable insight from their operational data. Over the last decade, companies have started to develop machine learning, cloud computing, mesh network, and edge computing services to the industry (Cloud, 2018). In order to cut cost, increase production and increase safety it is of great interest to automate certain types of tasks. Companies are already deploying smart technology throughout the processes, and that trend will continue in the future (Birkeland, 2017). This paper aims to discuss what operations are possible to automate, and what these tasks require in terms of robot specifications. Moreover, a discussion on how present robots meet these requirements, and how an automation will affect cost, production rate and safety are performed. All of this aimed to build a system that provides a seamless integration of man, robot, technology and organization.

2. METHODS

This article is a literature review within the domain of offshore inspection and maintenance. To find relevant articles regarding the topics, search words such as "Robotics + inspection and maintenance", "Oil & Gas offshore inspection" and "Autonomous manipulation" have been used. The site that has been most used is Google

Scholar. During the previous 10-15 years, researchers have been investigating whether robots can enhance the operations at Oil & Gas platforms. Even though there aren't many publicly available articles, the ones that are published are pretty good, which led to a good starting point for this literature review.

The framework for this article is mainly based around the articles; "Mobile Robots for Offshore Inspection and Manipulation", by Graf and Pfeiffer (2007), "Exploring robotic applications in offshore Oil & Gas industry," by H.Chen, S. Stavinoha, M. Walker, B. Zhang and T. Fuhlbrigge (2014), "A survey on mobile robots for industrial inspections." By Andreas Kroll (2008) and "A Robotic Concept for Remote Inspection and Maintenance on Oil Platforms" by Erik Kyrkjebø, Pål Liljebäck and Aksel A. Transeth to gain more information about existing solutions and research about the future. In addition, other sources are used to complement, and gain perspective on automation of offshore operations.

3. BACKGROUND

To get started it is important to build a solid foundation on how far the development of mobile robots have come. Therefore, this section will give an introduction on why inspection and maintenance are of importance, what mobile robot prototypes exists, what the different tasks are, how current operations on offshore platforms are performed, and ends with potential savings.

3.1 Inspection and maintenance at Oil & Gas platforms today, and why it is important.

Visual inspection and maintenance tasks are very important parts of the safety and quality control on process facilities. Even though a plant is equipped with numerous sensors that provide internal state information, they can become uncalibrated or fail over time. An external validation of the sensor values performed during an inspection will act as a second security net to detect these potential errors (Kyrkjebø, Liljebäck, & Transeth, 2009). New refinery projects are rare, and these days operational plants reach an older age. It is not uncommon with pipework as old as 30+ years. Industrial plants are extremely important to keep in a good condition(Kyrkjebø et al., 2009). After the Deep-Water Horizon accident in 2010, BOEMRE (Bureau of Ocean Energy Management, Regulation, and Enforcement) introduced new mandatory maintenance and inspection programs for Oil & Gas facilities. Other types of industrial plants have implemented similar programs. The result of these regulations is a cut by a factor of four in maintenance related downtime in refineries and halved in nuclear power plants. On the other hand, it leads to increased cost of daily operations(Kroll, 2008).

There are three types of inspections in plants. Inspections regarding 1) safety and maintenance, 2) security and 3) product quality. The aim of this article is to focus on the first category, regarding safety and maintenance. Such tasks are mainly related to the human senses; smell, noise and eyesight. Examples of what the inspections aim to discover, with special attention to material health, are:

- Cracks
- Corrosion
- Leaks
- Bearings
- Eccentricities
- Lubricants
- Calibration of instruments
- Fouling

The main cost driver when it comes to maintenance on Oil & Gas platforms are corrosion(Kroll, 2008). Only in the US, it accounts for 276 billion USD in extra cost each year. Corrosion can potentially lead to a major breakdown and result in catastrophic accidents. Pipes and vessels are of high importance to keep in good condition, and Non-destructive testing methods, are used during inspections to determine the wall thickness, hence the overall health of the equipment. Abnormalities such as cracks and leak detection are also of great interest. Pressurized components are often designed to leak before they break, which means it is possible to detect a failure at an early stage. Third, leakages account for about 23.5 % of all damages in a chemical plant. It is therefore right behind corrosion as the most expensive damage symptoms (Kroll, 2008).

3.2 Mobile robots for inspection and maintenance

Robots performing inspection and maintenance tasks aren't a new topic. In some industries and on specific tasks, such robots were used as early as in the 1960s. However, those robots are following predefined paths or rail systems, and are usually guided through the tasks manually by an operator. What diversifies these robots from what is required by an autonomous robot at an Oil & Gas platform, are issues regarding navigation, functionality, localization, measurements and autonomous operation (Kroll, 2008).

Three of the most promising prototypes for inspection and maintenance are the Sensabot, the Argonaut and the Fraunhofer MimroEX robot. Sensabot, figure 1, is developed by Carnegie Mellon University. It is probably the most mature robot made this far since it is already in operation and is designed for process facility environments (Peerless, I., Serblowski, A., & Mulder, 2016). This entails that it should function even when temperatures range from 40°C to -35°C. It also needs to handle corrosive, toxic, foul-smelling and explosive gases. The Sensabot meets the required explosion-safe certification, called IECEX. To navigate between different levels it uses specialized elevators, ramps, and a rail system. For inspection purposes, it can measure gas concentration, temperature, vibration, and is equipped with a microphone, lidar and video to detect obstacles (Chen, Stavinoha, Walker, Zhang, & Fuhlbrigge, 2014).

Figure 1: Sensabot robot (Peerless, I., Serblowski, A., & Mulder, 2016).

The Argonauts robot, figure 2, is made by a team of engineers from TU Darmstadt and taurob GmbH (Kohlbrecher & Von Stryk, 2016). It also has explosion safe certification and is designed mainly to perform visual inspection tasks. Nevertheless, it is a modular concept and can be equipped with a mechanical manipulator arm that should be able to intervene with equipment. The Argonaut won a challenge hosted by Total Oil Company with intention to inspect Oil & Gas platforms (Kohlbrecher & Von Stryk, 2016). The plan is to develop this robot further and make it start operating on Total industrial sites by 2020.

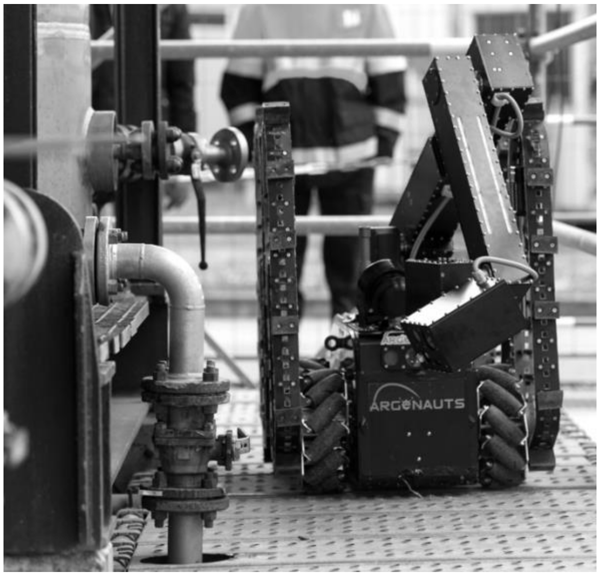

Figure 2: Team Argonaut's Robot (Kohlbrecher & Von Stryk, 2016).

The Fraunhofer MIMROex robot, figure 3, is an inspection and maintenance robot developed by Fraunhofer Institute of Manufacturing Engineering and Automation (IPA). Instead of using a 2D lidar system like the Sensabot and Argonaut robots, it uses reflective tape as well as pipes and poles for navigation and localization. It is equipped with a laser scanner to perceive the environment, six-axis robot arm with an attached camera for inspections, stereo microphone, gas, and fire detector. It uses WIFI and Bluetooth to communicate with both a tablet and a computer for the operator. It has been tested at an offshore oil platform, and the result was promising even though it had some issues with connectivity and navigation in the harsh environment. It navigated safely, without compromising the security of offshore workers, or the process (Bengel, Pfeiffer, Graf, Bubeck, & Verl, 2009).

We see that all of the three robots are in a pretty early stage of development. The current focus is on making them perform visual inspection, but they are intended to be able to physically intervene with equipment in not too long. Out of these three robots, the Sensabot and Argonaut seems to be superior to the Fraunhofer MimroEx robot. Nevertheless, both of these robots have to overcome a number of challenges in order to both inspect and maintain equipment at Oil & Gas platforms.

Figure 3: Fraunhofer robot (Bengel et al., 2009).

3.3 Inspection and Maintenance on an Oil & Gas platform

Graf and Pfeiffer identified the most important tasks performed at the oil platform in their article "Mobile robots for offshore inspection and automation.", and split them into two categories; scheduled tasks and occasional tasks (Bengel et al., 2009).

The scheduled task again split into three categories, which are inspection, monitoring and maintenance. Each one of them contains tasks like gauge readings, valve and lever position readings, gas level detection, leakage monitoring, acoustic anomaly detection, surface condition monitoring, intruder monitoring, sampling, alarm system testing, cleaning, refilling and pigging.

The most frequent occasional operations are often related to valve manipulation or actions after a leakage or fire is detected. Examples of such are: (1) Valve and lever operations, including change of pressure, change of flow rate, and start or stop of equipment operation. (2) Gas leakage including identify, locate and notify, stop of operations, and stop of leakage and monitor the improvements. (3) Fire detection including identifying, locating, and evacuating the area plus firefighting. What we can see from this set of operations, is that most of the tasks are possible to perform without having manipulation capabilities of physical assets.

All of these tasks can be split into three main categories, arranged according to how advanced the technological solution needs to be. From the simplest to the most advanced, the different categories are inspection, manipulation and operation.

Inspection - low level
• Visual inspection with camera.
• Surveillance robot.
• Explosion-safe certification.

Manipulation - moderate level
• Valve manipulator.
• Sample taker.

Operation - advanced level
• Autonomous navigation.
• Interaction with equipment.

Robots can perform a significant part of the tasks an offshore maintenance and inspection worker normally performs. Considering also that the robot will eliminate the risk of having human operators in such hazardous environments it's clear that it's of great benefit to use mobile inspection robots in offshore operations.

3.4 Oil & Gas offshore standards, and possibilities for a mobile robot.

Due to HMS requirements, no passage should be less than 0.745m, and the minimum height is 1.5m. This means that the robot needs to be able to operate within the same space.

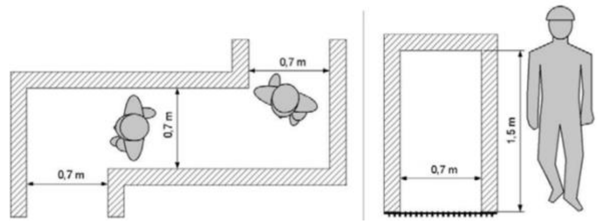

Figure 4: Space constraints, obstacles, and reference measures (Bengel et al., 2009).

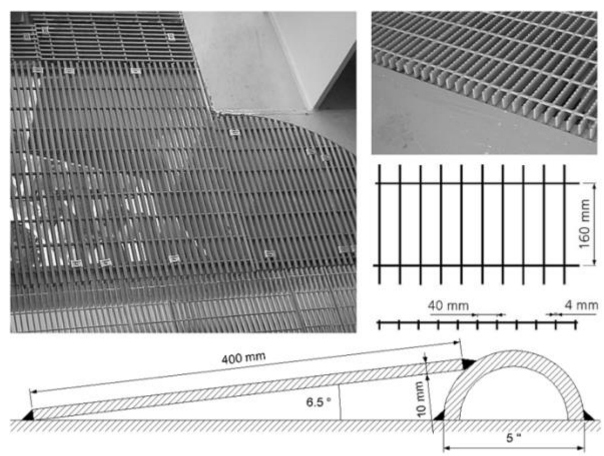

Figure 5: Confined spaces and navigation reference (Bengel et al., 2009).

When developing an offshore mobile robot it must be designed for the worst case scenario. This means it has to face the tallest obstacles, holes, gaps, smallest openings and steepest slopes. The floor usually consists of steel plates and steel gratings where steps, sharp edges, holes and corrosion are common. In addition, there are almost no walls that can be used for laser navigation, lots of moving objects that are important to detect and avoid (Bengel et al., 2009).

In order to cope with these constraints, The Fraunhofer Institute made a list of hardware specifications for their robot, the Fraunhofer MIMROex robot. Figure 6 presents their set of hardware specifications.

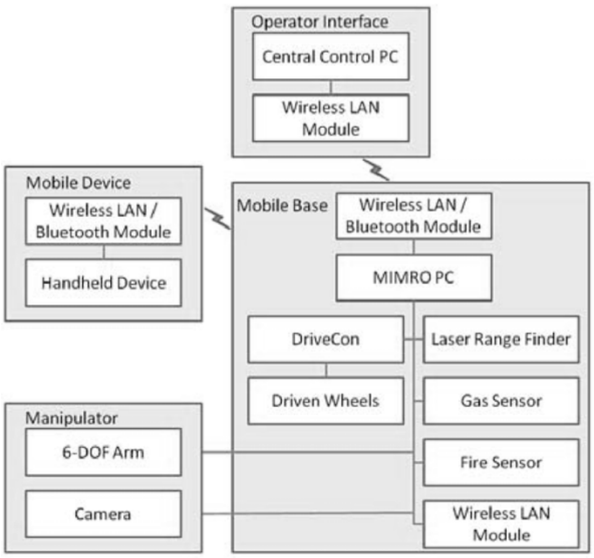

Figure 6: Inspection and Maintenance on an Oil & Gas platform (Bengel et al., 2009).

Both the Argonaut and Sensabot have similar functionality to the Fraunhofer MIMROex robot regarding navigation and inspection. What currently makes the Argonaut superior, is that it is intended to be the first fully autonomous robot operating at an offshore Oil & Gas platform. Whereas, the Sensabot and Fraunhofer MIMROex are only semi- autonomous. This means that they can do some of the navigation, and operating autonomously, but have to be controlled by an operator performing specific tasks.

On the Oil & Gas platform there are a number of factors that have to be considered. In order to enhance safety, be durable and robust, the robot needs to be designed for the harsh environment it encounters during daily operations at the Oil & Gas platform. Hence, it needs to be explosion proof, salt waterproof and weatherproof. The robot also requires high tolerance of extreme temperatures, humidity, direct sunlight, winds, and explosive, toxic and corrosive gases.

In order to fulfill the above-mentioned requirements, the robot needs to be equipped with several sensors and other hardware elements, in addition to state of the art software.

3.5 How operations on Oil & Gas platforms are performed today.

On an Oil & Gas platform named Ivar Aasen there are over 100.000 sensors continuously measuring one specific value each, i.e. temperature, pressure, distance or vibration. On other Oil & Gas platforms, the number of sensors could be multiplied by a factor of 3 or 4. These sensors are monitored, and the system will alert the operator whenever the values deviate from the desired operation limits. It is therefore of high importance that these sensors are well calibrated at all times and measure the correct value. In order to do this, manual inspections have to be performed. Today, this work is mainly based on manual labor consisting of forms and checklists.

Recently, the Norwegian startup Cognite have launched the first publicly available platform for sensor data from the industry. Their aim is to cut cost, improve safety and increase production. Mainly by utilizing smart maintenance and inspection technologies. At first, Cognite started with sensor data from Ivar Aasen, and will continue with other facilities in near future.

3.6 The Cognite Data Platform

The Cognite Data Platform is a software solution that aims to liberate industry data (Cloud, 2018). The platform ingests data from heavy industry operations in order to generate more value for customers. It is therefore of interest to Cognite that an inspection and maintenance robot can validate sensor data as well as 3D-scan the facilities. All of this in order to more reliably detect anomalies, update digital twin 3D-models, detect leaks, corrosion, etc.

Cognite are currently developing multiple applications on top of their data platform, including a checklist for operators. A similar checklist should be developed for the industrial robot. In this checklist operators could be able to specify tasks and intervals, as well as read recordings and reports on completed tasks.

3.6 Potential savings

Studies show that cost of operations could be significantly reduced by using data and monitoring. This is because it will lead to insight that can prevent major downtime. GE claims a 36% decrease in unplanned shutdowns compared to other reactive approaches (Baker Hughes, n.d.). Figure 7 shows how cost of unplanned downtime is affected by maintenance approach (Baker Hughes, n.d.).

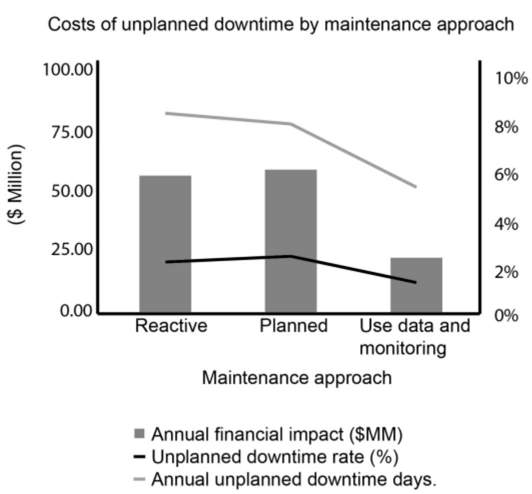

Figure 7: GE's estimates on cost of unplanned downtime. (Baker Hughes, n.d.).

The Kimberlite study shows that an unplanned downtime lasting a total of 3.65 days per year could cost organizations 5 million USD each year (Baker Hughes, n.d.). Between year 2007 until 2014, the operational costs have increased drastically on offshore installations in Norway. It has increased from 51 Billion NOK to 67 Billion NOK, and a large part of these expenses consists of maintenance and repair costs (Oljedirektoratet, 2015). It is believed that this could be significantly decreased by making robots perform condition monitoring. On the other hand, investment- and development costs related to the robot will occur, in addition to maintenance of the robots themselves. Therefore, a robust and reliable design without adding unnecessary complexity to the entire system is required (Birkeland, 2017).

4. DISCUSSION

4.1 Existing robot solutions and required development.

The Sensabot is probably one of the most mature semi-autonomous robot systems that exists today (Peerless, I., Serblowski, A., & Mulder, 2016). It navigates autonomously to different areas and can be equipped with a manipulator arm as well as complex sensors to measure the desired assets. It is the only solution addressed in this article where the engineers actually have adapted the plant to cope with the natural constraints of the robot. I.e. the Sensabot travels between floors using custom-made elevators and a cog rail system. Otherwise it is only capable of navigating on flat surfaces (Peerless, I., Serblowski, A., & Mulder, 2016).

The Argonaut robot is a competitor to the Sensabot. A similar prototype to the Argonaut robot has been tested for nuclear and chemical environments for some time. This gives the Argonaut robot an advantage when it comes to further development for Oil & Gas service. In addition, the robot is built in a modular way, so it’s possible to customize it further. As the only robot out of the three mentioned, it has the capabilities of navigating between different floors using the stairs and doesn’t require customized infrastructure (Birkeland, 2017). Total has stated that their intention is to deploy the Argonaut robot at industrial plants by the end of year 2020.

The Fraunhofer robot is the largest of the three. It is only capable of navigating on flat surfaces. It is semi-autonomous like the Sensabot. This means it can navigate autonomously, but needs assistance when it is going to intervene with objects (Birkeland, 2017). During tests, the Fraunhofer robot had issues regarding connectivity and navigating due to rough weather conditions.

All the existing robots are mainly focusing on visualization and inspection tasks. As aforementioned, these tasks belong to the lowest level of how advanced they are, namely "Inspection - low level".

Even though these robots have some sort of manipulation capabilities, the reliability, efficiency and simplicity of these are unfortunately not optimal. After these robots prove successful at inspection, the next step will be to develop reliable manipulation capabilities. There are several articles researching how robots can physically intervene with equipment in an efficient way. The challenges that arise seem to result from the design of the different assets. They were initially designed for human operators. Going forward, it is therefore the right time to put effort into developing the Robot-Centered Design framework in order to redesign assets to meet robot constraints.

4.2 Design of the robot, the platform or both.

When designing a robot to meet the constraints of an Oil & Gas platform, there are issues to overcome. It is important that the wheel or track system are designed to meet the floor condition. The floors can be slippery and wet and have corrosion holes and bumps. Restrictions due to size also need to be taken in consideration. Advanced sensors are required to maneuver and perceive surrounding pipes and flanges in order to avoid collision. The robot could have a stair climbing functionality and low center of gravity.

For the robot to be able to intervene with equipment originally designed for humans, it needs to be equipped with a manipulator that has human-like capabilities and functionality. Examples of tasks this manipulator should be able to do is; turn valves, operate operator panels, clean and take samples.

On the other hand, to fully design a robot for an Oil & Gas platform that was intended and customized for human users, can be challenging. One of the greatest challenges designers are fronting, is that we are humans, and often more self-centered than we would like to admit. Our knowledge about others are based on our own perception and understanding of the world. Often, when trying to design something for other users, we are unable to see past our own needs and preferences and end up designing a product that doesn’t fit the targeted group as intended.

Human-Centered Design is a common design and management framework to develop a design that enables the human user to function at the highest possible level when interacting with the product. This means factors like ergonomics, affordance and usability need to be considered in every step of the design process. In future automation, a new stakeholder has to be taken into consideration, namely the robot. Whenever it is intended that both humans and robots can interact with the physical, it is important that both the stakeholders are considered in a more complex design process aiming to enable each of the users to function at their highest level possible.

Even though some robots are made with human-like appearance, humanoids, robots are forever going to be something else than human beings. Robots will have different preferences, algorithms controlling their actions, mechanisms, sensors to perceive the environment and specialized grippers to manipulate the world. Some of the simplest tasks that human beings perform are only simple because the products we intervene with are custom made for us. That’s why designers have to ask themselves the question whether they will continue to design products exclusively for human beings and the past, or for the future with both human and robot preferences. As a quick example, when designing doors with connected automatic open/close mechanisms, the robot could intervene with it even without having a single physical manipulator mechanism. Isn't that something all kids have dreamt about? Being able to control the physical world with our mind. That is actually possible for robots, if designers actively take them into consideration when designing future appliances.

5. FINAL REMARKS

When designing Oil & Gas platforms for the future, it is important to consider whether existing designs have the optimal function and affordance for all the stakeholders. That way, designers will be able to design for all the potential users, and not only the human part.

As discovered, inspection and maintenance tasks on industrial plants are often repetitive and high precision and can benefit from having functionality beyond the abilities of human senses, i.e. contactless heat sensors, anomaly detection, and gas detection. This indicates that companies can greatly increase safety and production rates as well as decrease overall cost by applying robots. Both Sensabot and Argonaut deal with the constraints of operating at an Oil & Gas platform in a satisfactory way. Sensabot is the only robot where the platform itself has been developed to fit the constraints of the robot. I.e. with custom-made rail cog systems and elevators for the robot. It would be interesting if both a redesign of the platform and the design of the robot was coordinated to an even larger extent.

The overall development of autonomous inspection and maintenance robots is still in a pretty early phase. A dominant design isn't yet established. This means that the field still needs research. For further development, iterations need to be performed in order to develop the most robust, efficient, reliable and safe robot for inspection and maintenance.

The existing robot prototypes described in this article make up a good starting point when it comes to future research, development and eventually the emerge of a dominant design. Requirements regarding safety, mobility and functionality are determined. Therefore, the next step will be to research the actual mechanisms, and whether the best thing is to design the robot for the platform, the platform for robots, or something in between in each individual use case. During the next iterations, physical design of both robots and assets, have to be developed in order to fit the requirements mentioned in this paper. If it succeeds, the overall operation will be enabled to function at the highest possible level.

REFERENCES

Bengel, M., Pfeiffer, K., Graf, B., Bubeck, A., & Verl, A. (2009). Mobile robots for offshore inspection and manipulation. In *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2009*. https://doi.org/10.1109/IROS.2009.5353885

Kyrkjebø, E., Liljebäck, P., & Transeth, A. A. (2009). A Robotic Concept for Remote Inspection and Maintenance on Oil Platforms. In *ASME 2009 28th International Conference on Ocean, Offshore and Arctic Engineering*. https://doi.org/10.1115/OMAE2009-79702

Kohlbrecher, S., Meyer, J., Graber, T., Petersen, K., Klingauf, U., & Von Stryk, O. (2014). Hector open source modules for autonomous mapping and navigation with rescue robots. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. https://doi.org/10.1007/978-3-662-44468-9_58

Cloud, G. (2018). Cognite: Creating real-time models of Aker BP. Retrieved November 13, 2018, from https://cloud.google.com/customers/cognite/

Oljedirektoratet, N. (2015). *Driftskostnader - status og utvikling*. Retrieved from http://www.npd.no/no/Publikasjoner/Rapporter/Driftskostnader---status-og-utvikling-/

Baker Hughes, G. (n.d.). Impact of digital on unplanned downtime study. Retrieved from https://www.bhge.com/sites/default/files/2017 - 12/impact-of-digital-on-unplanned- downtime-study.pdf

Birkeland, M. (2017). *Evaluation of the potential for automa- tion and robot technology, with focus on condition monitoring on static systems for topside offshore facilities.* University of Stavanger.

Kohlbrecher, S., & Von Stryk, O. (2016). From RoboCup Rescue to Supervised Autonomous Mobile Robots for Remote Inspection of Industrial Plants. *KI - Künstliche Intelligenz*, *30*. https://doi.org/10.1007/s13218-016-0446-8

Peerless, I., Serblowski, A., & Mulder, B. (2016). A Robot that Removes Operators from Extreme Environments. *Society of Petroleum Engineers.*

Shukla, A., & Karki, H. (2015). Application of robotics in onshore oil and gas industry-A review Part I. *Robotics and Autonomous Systems*, *75*. https://doi.org/10.1016/j.robot.2015.09.012

Kroll, A. (2008). A survey on mobile robots for industrial Inspections. *Proceedings of the Int. Conf. on Intelligent Autonomous Systems IAS10, Baden-Baden, Germany*. https://doi.org/10.3233/978-1-58603-887-8-406

Chen, H., Stavinoha, S., Walker, M., Zhang, B., & Fuhlbrigge, T. (2014). Exploring robotic applications in offshore oil&gas industry. In *4th Annual IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems, IEEE-CYBER 2014*. https://doi.org/10.1109/CYBER.2014.6917525