Remote inspection and intervention

Remote robotics at work in harsh oil and gas environments

CHARLOTTE SKOURUP, JOHN PRETLOVE – The global demand for oil and gas remains high and will do for the foreseeable future. However, the industry is facing a number of challenges, including the struggle to retain production levels and access reserves that are often in extremely demanding environments. These challenges have led to calls to boost the level of automation in the oil and gas industry while maintaining the focus on health, safety and the environment. Many oil and gas facilities are already remotely operated during normal operation, but highly skilled people are still needed to perform specialized work, such as maintenance and repair tasks during operation and planned shutdowns. To benefit from an increased level of automation in this area, which would protect humans from hazardous environments and potentially dangerous tasks, a combination of remote operations combined with telerobotics is required. In answer to this demand, ABB has developed a robotics-based remote automation system prototype that is capable of performing inspection and maintenance of an oil and gas process module. This compliments existing automation system and work practices and enables the operators to perform the same job but from a safer location.

The level of automation in different industries can vary quite dramatically. Within the manufacturing industry, for example, tasks that lend themselves well to being automated are those that are repetitive and repeatable; require high accuracy; are routine and often heavy; and dirty and dangerous to workers. In the oil and gas industry, the degree of automation varies between the different phases of oil exploration, extraction and production, and between the various disciplines and regions. Levels of automation range from almost non-existent (field operators reading in-field analogue measurements) to advanced process and safety control systems that have automated large, complex and dynamic processes. In general, however, most oil and gas facilities operate with hybrid or mixed levels of automation.

Challenges within the industry, such as lower recovery rates, the difficulty in accessing fields and the exploration of


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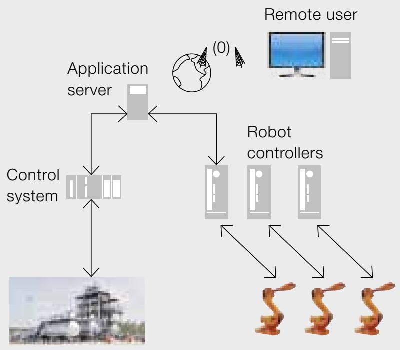
1 Physical and cognitive tasks

The mechanical or physical level of automation (LoAphys) concerns the physical work content, which is still relatively low for all tasks in the field of oil and gas installations. Teams of operators and various specialists execute the various physical tasks using their hands and tools. Some tools, such as infrared cameras that take temperature images from the outside of the process and equipment, are rather advanced.

Levels of cognitive task automation (LoAcogn) vary across the entire spectrum depending on the task. For example, when unforeseen situations occur, operators have to use their cognitive capabilities to understand the current situation, predict future states and make decisions concerning further actions. At the other end of the scale, the automation system automatically handles the immediate shutdown of the process or parts of the process without human intervention when an emergency situation occurs. Human intervention is necessary after the shutdown to access the problem and restart the process.

3 The outdoor robot test facility in Oslo

2 The robotics system architecture



ABB's robotics-based remote automation system prototype is capable of performing inspection and maintenance of an oil and gas process module.

unconventional reserves have put the need for raising the level of automation high on the agenda. Remote operation during normal operation is already a reality for many facilities. However, highly skilled people are still needed to perform critical equipment inspection including verification, maintenance and repair tasks during operation and planned shutdowns in what are often considered hazardous environments. To increase the level of automation in this area requires a combination of remote operation and telerobotics.

The introduction of robotics technology will influence roles, responsibilities and work tasks. For a start, the presence of robotics does not mean humans become redundant: They will remain a vital and irreplaceable part of the process with the main focus on cognitive rather than physical tasks → 1. Therefore, it is crucial to decide on the roles, task allocation and levels of automation between the human and the automation system incorporating the robot. An adaptive, variable, approach to automation has been suggested as a way to trade off the various benefits and costs associated with automation and manual control. In any case the main design principle of the human/robot system is to enable the operator to focus on the tasks that need to be performed and to perceive all controllable robots as physical enablers in the field to execute these tasks. This correlates with the relationships between control room operators and field operators in today's process plants. In the robotized system, the human operator remains responsible for the process and its operation while the robot performs the physical tasks with sensors and tools in the field.

Remote inspection and intervention of process infrastructure

As part of its strategy for exploring and developing new concepts for extended remote operation, ABB has already developed a robotics-based remote automation system prototype that can perform inspection and maintenance of an oil and gas process module. The system is capable of remote visual inspection, remote verification, remote automatic pig handling, and remote testing and calibration of process components. The philosophy behind this remotely operated robotics system is that the robots are integrated in the field and seen as assets in the control system. They serve as the physical tools and the operators' extended "eyes, ears and hands" within a hazardous process environment. Within the control system, the remote operator interacts with the robot using a human-robot interface (HRI) through which the different tasks the robototics system is expected to flawlessly complete can be defined and initiated. The results are then returned and presented by the control system to the operator.

4 On-site customer installation of the robotics system

Test facilities
Indoor and outdoor test facilities exist to simulate, test and verify new on-site test configurations. The indoor test facility housing the prototype is a unique lab environment used to demonstrate, test and evaluate concepts and solutions that could be of interest for future oil and gas facilities. The prototype setup comprises three ABB robots, one gantry-mounted IRB 2400 and two rail-mounted IRB 4400, as well as a full-scale separator process module (see title picture). All robots have access to multiple tools that can be changed automatically using pneumatic tool changers. Some of the sensors are carried on the robot arm, such as cameras for monitoring the work, whereas application specific sensors are mounted on the tools. In the lab setup, one robot is typically used for inspection and two for maintenance tasks.

The robots are controlled by robot controllers – all of which are accessible from an application server – while a control system controls the process. The application server runs path-planning algorithms and handles communication with the users ➔ 2. One of its main tasks is to translate the commands given by the users to instructions for the controllers and vice versa.

Computer vision and optimization algorithms have also been implemented to cope with the uncertainties of moving instruments and apparatus in harsh environments. Because these objects can move or become temporarily or permanently mechanically deformed, their position and orientation are not fixed and constitute an uncertainty that needs to be taken into account when the robots interact with the process.

Three main aspects of telerobotics are tested in the lab: autonomous control, semi-autonomous control and manual remote control. Autonomous control is ambiguous and could be described as a continuum from fully manual control to fully autonomous control. In other words at the lowest extreme, humans make all the decisions and perform the necessary activities without any assistance from the control system; at the other extreme the control system makes all the decisions and executes actions without any human involvement. An example of fully autonomous control is the frequent inspection rounds that follow a pre-defined schedule. As well as being fully capable of performing this, the control system can also decide which robot is available for each task, select the proper sensor, move the robot with the sensor safely to the various inspection points and take the measurement. The operator is only notified when deviations from "normal" values are detected. Otherwise the measurements are stored in databases and the necessary reports generated. Manual control is necessary, for example, to remove ice that has formed on a valve. During semi-autonomous control, the control system or the operator initiates tasks for the robots. The (remotely-located) operator utilizes a 3-D process model as the interface to the process to define and initiate tasks for the robots and retrieve the results from such tasks. This has been tested by operating the test facility remotely from various locations, including Houston in the United States and Stavanger in Norway. The tests have proven that the technology works consistently over several days, even over a public network with limited bandwidth.

The outdoor test facility is used to further simulate, test and verify concepts that are developed and commissioned in the indoor lab to suit real on-site test configurations before delivery ➔ 3.

A practical application – scraper handling

Based on the specialised lab facilities and experience gained within this novel field, Shell Global Solutions and ABB, in a collaborative project, have recently developed, tested and verified an automated solution for on-site scraper handling.

In the robotized system, the human operator remains responsible for the process and its operation while the robot performs the physical tasks with sensors and tools.

The purpose of the project is to demonstrate the use of robotics technology for handling scrapers in a real process environment.

5 The ATEX certified ABB IRB 5500 robot at the scraper station on a cold day during the demonstration period

The ABB and Shell demonstrator has shown that robots can be used in oil and gas facilities to perform high precision operations in all kinds of weather.

A scraper, or pig, is a device that is sent through a pipeline to inspect or clean the inside of the pipe. Each scraper consists of elastic, over-dimensioned disks that seal the pipe, while pressure from the transported product (oil or gas) pushes it forward. Typically, scrapers are manually inserted and extracted at special stations along oil and gas pipelines; extracting a scraper is particularly risky for the human operator.

A scraper will accumulate debris as it travels through the pipeline, which itself widens into a barrel form at the receiving end so that the scraper can be extracted. This barrel needs to be depressurized and drained before the door can be opened. The accumulated debris sometimes causes the depressurization process to fail, causing the scraper to be ejected with great force, as has happened on several occasions. In addition, in facilities with a high degree of poisonous gas in the reservoir, such as H2S, scraper-handling operations have to follow very strict procedures, making these operations undesirable from a cost, and in particular, from a health, safety and the environment (HSE) perspective.

The ABB/Shell solution consists of an ATEX certified industrial ABB robot (IRB 5500), which has been equipped with a tool specifically designed for scraper handling. The tool's sensors, together with the robot's built-in sensors, guide the robot and verify that operations can be safely performed. The demonstration used a standard and unmodified scraper barrel and door. With safety as a priority, an operator interface was installed next to the robot, enabling a trained operator to acknowledge each step of the process before the robot was allowed to execute the subsequent step.

The entire demonstrator concept was first installed, commissioned, tested and verified (ie, the robot was used to launch scrapers into the barrel and receive them upon arrival) at the outdoor test facility in Oslo. Before being shipped to the demonstrator site, the Nederlandse Aardolie Maatschappij (NAM) BV Schiedam's Gaag facility outside Rotterdam in the Netherlands, it passed a pre-delivery acceptance test with participants from both ABB and Shell → 4. The on-site tests (ie, extraction of the scrapers only) were performed during winter, in snow, rain and sunshine and in temperatures that fell to minus 10 °C → 5.

During a typical test → 6, the robot first verifies that initial safety critical preparation steps have been executed by ensuring that the door lock and handle are in the expected locations (ie, locked and closed). A proximity switch integrated into the tool is used for this purpose. The robot then unlocks and slightly opens the barrel door to allow debris and residual oil to pour onto a drain table in front of the barrel before fully opening the door. It inserts the tool into the barrel and begins to search for the scraper. Inbuilt functionality in the robot controller halts robot movement on state change of an input signal. When the scraper is found, the robot extracts the scraper and places it on the table. The door is then closed and locked before the robot returns to its home position.

Some simplifications were imposed on this demonstrator to fulfil the requirements. To begin with, the number of robotized tasks related to the scraper operation made up a subset of the complete operation of scraper extraction. Some of the subtasks outside the scope of this project included the opening and closing of valves, running drain pumps and removing vent plugs (after which the scraper extraction task starts). All these steps can, however, be automated with existing technology. The robotics demonstrator was also restricted to retrieving scrapers located relatively close to the door (ie, less than 0.5 away). In reality, scrapers may be located up to two

6 The robot performing its scraper handling task on site

meters from the door. Finally, the demonstrator was powered with a stand-alone diesel generator and produced its own instrumented air to avoid major modifications to the plant drawings.

With this demonstrator, ABB and Shell have shown that robots can be used in oil and gas facilities to perform high precision operations in all kinds of weather. More importantly, however, this demonstrator has enormous potential to reduce the HSE risks that these operations represent.

The challenge ahead

Future extraction and production of oil and gas are facing a number of challenges, such as lower recovery rates, fields that are difficult to access and the exploration of unconventional reserves in combination with more challenging reservoirs. These challenges indicate that an increase in the level of automation at an installation – maybe to the point that oil and gas facilities are unmanned – is all but inevitable, especially if the continuous demands for improved safety are to be properly addressed. If this is the case, then the inspection and maintenance tasks, verification, tests and calibrations currently carried out by field operators and maintenance staff will eventually have to be done by robotics integrated into the control system. While this has the potential to improve safety, it will also need to be efficient to secure added value and optimal production within a distant and harsh environment.

Satisfying the criteria of safety, efficiency and cost effectiveness in a solution is not an easy task and may require novel technical solutions, new working practices and business models. There are, however, a few fundamental factors that influence a successful outcome. To begin with, close collaboration with end-users and customers within the oil and gas market allows the projects to focus on real problems and challenges faced by

> As well as increased safety, ABB's remote automation system prototype has the potential to help contribute to higher uptime and increased profitability of a facility.

the industry. This helps to provide well-defined customer requirements. The next step is deciding if these can be met using existing or emerging technologies or a combination of both. To meet the various challenges of such a complex robotics system, a step-by-step approach is necessary during the development phases, which also involves validating the technology in increasingly demanding and realistic settings.

This is the approach adapted by ABB during the development of its remote automation system prototype. The initial results of this novel robotics concept are very promising. As well as increased safety, another long-term aim is that it will enable more consistent and reliable operation, which in turn will contribute to higher uptime and increased profitability of the facility.

Charlotte Skourup

John Pretlove

ABB Strategic R&D for Oil, Gas and Petrochemicals

Oslo, Norway

charlotte.skourup@no.abb.com

john.pretlove@no.abb.com

Title picture

The prototype setup shown is used to simulate, test and verify concepts and new test configurations. It generally comprises three ABB robots (one for inspection and two for maintenance operations).