ROBOTICS, SENSING AND PROCESS CONTROL CAPABILITIES
INTRODUCTION
A NEW ROLE FOR ROBOTICS
MAKING SENSE OF SENSING
THE POWER OF PROCESS CONTROL
THE FUTURE
Introduction

Robotics, Sensing and Automation will play an increasing role in driving safety and efficiency in the energy industry.
Global energy demand is surging. Oil and gas are likely to make up a significant proportion of the world’s energy supply for decades to come, but the industry is facing a number of significant challenges. Many new hydrocarbon reserves are located in harsh or remote locations, which make them more challenging and expensive to develop. In addition, many of these newly discovered assets contain hydrocarbons that require complex processing.

At the same time, companies are facing the prospect of staff shortages as experts retire from the industry. This has placed a fresh emphasis on centralised decision-making that minimises the need for staff to travel to remote or harsh locations and helps make operations as safe as possible.

Technology will be a key enabler in meeting these challenges. This document reviews three areas where Shell is introducing new technologies that are expected to make a substantial contribution to the success of future operations – robotics, sensing and process control.

Recent advances in these disciplines will enable the industry to minimise risk to personnel in harsh, frontier locations, enhance and accelerate decision making to minimise deferment and reduce facility turnaround times, achieve and maintain performance excellence in process operations. They will also help to increase productivity and efficiency and boost asset integrity.
ROBOTICS

Until recently, robotic systems were considered appropriate only in situations where humans could not venture, such as the use of ROVs in deep underwater settings. Today there is a growing recognition robots can be applied in other areas and that robotic technology is becoming much cheaper.

Robotics is important for the oil and gas industry because human exposure to risk has become the bottleneck in many projects. Operators are focusing on inherently dangerous tasks that are currently done by humans and simple tasks that are difficult or expensive for humans to accomplish. Over the next few years, many of the routine inspection tasks undertaken by humans in harsh or remote frontier areas will be conducted by robots. Robotic systems have the potential to deliver a range of safety and commercial benefits and Shell is working with industry partners, vendors and academic institutions to develop novel robotic systems for specific applications.

These include the Sensabot system for plant inspection and first response situations, the introduction of remotely operated aerial vehicles (ROAVs) to assess inaccessible structures and the Petrobot initiative that is developing robot systems for internal inspection of tanks and pressure vessels. Shell is also working with partners to develop autonomous underwater vehicles (AUV) for subsea infield inspection and pipeline inspection.

Shell's innovation in collaboration with Subsea 7 has created an Autonomous Inspection Vehicle that provides safer and better inspections in a more cost effective way.
Some equipment inspections involve safety exposure for personnel, problems with accessibility or an adverse impact on facility uptime. In recent years, Shell has pioneered the use of remotely operated aerial vehicles (ROAVs) or drones to conduct routine, but potentially difficult or dangerous inspections onshore and offshore, particularly those that involve working at heights.

Using ROAVs reduces HSSE exposure while enabling Shell to minimise production deferment, increase facility uptime and optimise shutdown timings as a result of gathering better quality data more frequently. ROAV deployments have included visual inspection of gas flares, vents and chimneys at refineries and gas plants in the Netherlands, Norway, Oman and the UK and offshore applications such as platform sub-decks and derrick tower inspections in the UK sector of the North Sea, see Table 1.

### Table 1: ROAV applications

<table>
<thead>
<tr>
<th>Asset</th>
<th>Country</th>
<th>Inspection scope</th>
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</thead>
<tbody>
<tr>
<td>Sarawak</td>
<td>Malaysia</td>
<td>Offshore live gas vent inspection using gas detection safety measure</td>
</tr>
<tr>
<td>Moerdijk</td>
<td>The Netherlands</td>
<td>Flare inspection (pilot project), chimney inspection</td>
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<tr>
<td>Pernis</td>
<td>The Netherlands</td>
<td>Flare inspection</td>
</tr>
<tr>
<td>Den Helder</td>
<td>The Netherlands</td>
<td>Flare inspection, hot oil furnace flue pipe Inspection</td>
</tr>
<tr>
<td>BLNG</td>
<td>Brunei</td>
<td>Marine flare stack inspection</td>
</tr>
<tr>
<td>Ormen Lange</td>
<td>Norway</td>
<td>Flare Inspection</td>
</tr>
<tr>
<td>Brent Delta</td>
<td>UK</td>
<td>Drill derrick inspection, module support frame Inspection</td>
</tr>
<tr>
<td>St. Fergus</td>
<td>UK</td>
<td>Live flare and structural inspection at height, aerial land survey</td>
</tr>
<tr>
<td>SPDC</td>
<td>Nigeria</td>
<td>Site survey</td>
</tr>
<tr>
<td>NAM</td>
<td>The Netherlands</td>
<td>Aerial surveys, live flare inspection</td>
</tr>
<tr>
<td>Bacton gas plant</td>
<td>UK</td>
<td>Chimney and communication mast inspection using on-board gas monitor</td>
</tr>
<tr>
<td>PDO</td>
<td>Oman</td>
<td>Site survey, live flare inspection</td>
</tr>
</tbody>
</table>

*Watch Cyberhawk UAV Inspection – Shell*

Remotely operated aerial vehicles (ROAVs) – often called “drones” – to examine some of Europe’s biggest energy plants.
SENSING

Sensing is crucial for the smooth running of modern oil and gas operations. In processing facilities and refineries, the ability to track factors such as temperature, pressure and vibration in real time enables operators to balance throughput and yield, to maintain plant safety and to optimise commercial performance.

New sensing systems are being applied to tasks such as process integrity monitoring, helping to reduce downtime and deferment and enhance equipment/process safety. The industry is using embedded sensing systems around plants or facilities to make more data available to the decision makers and to ensure that operations conform to environmental standards.

MINIMISING EMISSIONS DURING TIGHT GAS PRODUCTION

The production of natural gas can result in the release of methane into the atmosphere, known as fugitive methane emissions. There are concerns that tight gas production could increase these emissions. Methane is a very powerful greenhouse gas (GHG), 30 times more potent than CO₂ over 100 years and even higher over shorter timescales. Therefore, any potential increase in methane emissions must be treated seriously.¹

We implement technologies that prevent methane emissions during tight gas production. This includes a system known as green completion that captures emissions of methane, volatile organic compounds and other potential pollutants from wells. Infrared cameras are used at our sites to detect gas leaks.

¹ The production of natural gas can result in the release of methane into the atmosphere, known as fugitive methane emissions. There are concerns that tight gas production could increase these emissions. Methane is a very powerful greenhouse gas (GHG), 30 times more potent than CO₂ over 100 years and even higher over shorter timescales. Therefore, any potential increase in methane emissions must be treated seriously.
The main challenges in the development of advanced sensing technologies are creating low-cost systems that are rugged enough to survive in oil and gas operations, require minimal human intervention, have low power demands and can be linked using wireless communication protocols. Sensor technology will be a defining factor in creating the industrial internet of things, a structure that has the potential to revolutionise oil and gas processes.

Shell has established the Strategic Sensing Alliance to encourage closer cooperation between oil and gas companies as well as other industries, and to capture the status and planned development for emerging technologies and ensuring that everyone can realise the potential benefits.

**PROCESS CONTROL**

Advanced process control systems improve product yield and reduce energy consumption by maintaining process values such as temperature, flow rate, and pressure within a set range while also keeping them as close as possible to their optimal set points. These systems are increasingly being used in refineries, petrochemical plants and natural gas liquefaction trains.

The integrated model of process constraints built into advanced process control systems can keep the facility and its processes running more reliably and consistently than would be possible with intervention from a human operator.

Shell is working with leading companies to deliver more effective and streamlined tools for operators who wish to create bespoke process control applications and so enhance process performance. Collaboration with Yokogawa, for example, has produced a powerful new software suite – the Platform for Advanced Control and Estimation (PACE) – that will help to accelerate and simplify the tasks of designing, deploying, and maintaining advanced process control applications.

Security remains a top priority in the process control domain and Shell’s IT security collaboration with Cisco, coupled with our experience in systems management, enables us to maintain the security of operations in the face of cyber threats.
INTEGRATION IS THE KEY

Integrating technologies from the disciplines of robotics, sensing and process control will be a decisive step on the road to automation. Shell is active in all of these areas and has already applied the results of its research and development projects in many operational locations within Shell-operated facilities and in association with joint venture partners.

Success requires sustained levels of investment in research and development and a willingness to test new systems in the field. Shell’s open and collaborative approach to fundamental research helps to promote the effective sharing of knowledge and skills and maintain momentum in these crucial disciplines. We believe that bringing new tools together to create a network of interacting, intelligent systems will change how the oil and gas industry operates and deliver a step change in asset performance.
Robotics can address the ‘human exposure bottleneck’ by allowing staff to work at a safer distance while retaining or enhancing process integrity.
Over the past quarter of a century robotic systems have become a familiar part of modern life and have made crucial contributions to the success of many industrial projects. Robots are now well established in manufacturing workplaces, in laboratories and even in the world of medicine. This change has been driven by visions of improved safety and performance, some startling technological advances and the determination of companies, engineers and entrepreneurs.

In the oil and gas industry, robotic systems have been used for a variety of tasks since the 1960s, but the range of applications was generally limited to areas where direct human intervention was impossible, for example in extreme deepwater settings. Shell has always been a leader in the development and adoption of new technologies and today we are exploring the potential for robotic systems to be more widely used across our operations.

Experience shows that the inspection component of an inspection programme often accounts for less than 5% of the total work. Most of the time required is for other activities such as decontamination and cleaning of the location, opening and closing of access, removing internal furniture to allow access and reinstating it, erecting scaffolding for access and removing it, supporting inspection with a manhole guard and rescue teams. Inspection with a robot system reduces the intervention scope because it removes the need for all work that is related to human entry, leaving only surface cleaning and access opening.

RISK REDUCTION AND SAFETY—THE TOP PRIORITIES

Challenging environments are driving robotic developments within Shell at present. This includes operations in remote areas or those requiring personnel to deal with issues such as sour gas or extreme weather conditions. In these situations, special arrangements must be made to ensure the safety of personnel. This is expensive and can create an operational bottleneck.

Robotic technologies will address the ‘human exposure bottleneck’ by moving staff to safer places while retaining, or enhancing, process integrity.
Shell is developing and deploying robotic technologies in areas where there is scope to reduce risks to personnel while maintaining the highest levels of operational safety. At present, the key applications include using robots for:

- Surveillance
- Operations in confined spaces and hazardous areas
- Structural and fabric assessments
- External pressure equipment and pipeline inspection
- Subsea and marine deepwater equipment and pipeline projects.

For example, Shell has developed a robot system that can carry out many of the inspection and first responder tasks currently performed by people. The Sensabot is a robust, battery-operated system with a wireless command capability. It is designed to meet IECEx Zone 1 standards, which makes it ideal for facilities where the hydrocarbons being produced or processed contain high concentrations of toxic hydrogen sulphide (H₂S).

Robots must overcome some serious challenges in the oil and gas sector. Our robotic systems must be able to work outdoors in demanding, industrial settings and have IECEx, ATEX or ANSI/API ratings for explosive atmospheres. This presents a major challenge for many robotic companies – some suppliers will not participate in projects with explosive atmosphere requirements.

In addition, existing facilities were designed to suit human interaction and feature access solutions such as ladders that are not suitable for robotic systems. Robotic technologists are addressing these issues by developing more robust sensors, customised communication protocols and even a robot version of ladder access.

**SENSABOT: THE OILFIELD BABY-SITTER**

Sensabot is designed to be durable and reliable, with a 6-month period between human interventions. Its robust design means that it can cope with extremes of temperature from -35°C to +50°C and an IP-67 rating which means it is protected against dust and can operate safely outdoors even in heavy rain. The system’s environmental awareness systems include ten high-definition cameras, hydrogen sulphide and hydrocarbon detection, a thermal camera and sound and vibration sensors.

A functional prototype, the MARK 1 version, was built and trialled in Gasmer Texas. The results of the trials helped to define the modifications and additional requirements for the Mark II unit, which is currently undergoing IECEx certification and robustness testing prior to a planned deployment mid-2016.
HURDLES TO ADOPTION

Outside of subsea (ROV) applications, robots are largely unproven in oil and gas operations. Reluctance to disturb existing procedures, concerns about the consequences of failure, and the need for considerable upfront investment to develop systems that meet industry requirements mean that many companies are unwilling to trial new systems.

This cautious approach means that robotic technology is advancing much faster than the industry can adapt to it. This is often linked to a belief that given enough time the market will offer the solutions the industry needs. Experience suggests that this is not the case. The general market is not creating systems for specific oil and gas operations and ‘off-the-shelf’ solutions cannot meet industry needs.

The second hurdle to widespread adoption is the tight regulatory frameworks that govern oil and gas operations. For example, regulations insist that certain tasks can only be conducted by humans. While it is possible to combine human and robotic systems, the economic benefits of a robotic solution are greatly diminished if people are still closely involved in the activity. One of the key challenges for industry is, therefore, to work with governments and industry regulators to ensure that the legal framework reflects the current capabilities of robot systems.

Some authorities have already updated their regulations. For example, Shell recently conducted the first inspection project to be carried out under revised Dutch regulations on robotic inspection. This took place at the Pernis refinery in Rotterdam during November 2015.iii

DEFINING NEW APPROACHES TO HULL INSPECTION

Shell is participating in the Hull Inspection Techniques and Strategy (HITS) joint industry project, which involves working with classification societies, technology vendors and other oil companies to qualify existing technology for inspection tasks in confined spaces and hulls. This collaboration will help the industry to set objectives for hull integrity strategies and to translate these strategies into practical, effective and compliant hull integrity and inspection plans.

A second phase of the JIP will focus on identifying and developing selected inspection methodologies and testing them in the field. This will deliver recommendations and a cost-benefit analysis for implementing an optimised hull structural integrity strategy.

Costs and scalability are also crucial considerations in robotics. Developing and deploying a single robot is very expensive, but the introduction of a standard, modular or scalable robotic system would change the commercial landscape. New technologies and lower costs will enable robots to succeed in operational niches and locations that have not yet been considered.

The key challenges that the robotics and oil and gas communities will have to address are:

- Minimising the cost of robotic solutions to reduce capital and operating expenditure.
- Improving the effectiveness of collaboration between oil and gas operators and the robotic manufacturers and suppliers.
- Realising the economies of scale and establishing global service agreements that can transform bespoke solutions into standard industry tools.
CLIMBING THE TECHNOLOGY LADDER

Today, robotic systems are being used for oil and gas inspection and surveillance tasks and for maintenance operations such as cleaning and simple component replacement. In the future, there will be scope for robotic systems that work autonomously – following set patterns of action and performing routine tasks with the minimum of human intervention.

Beyond the introduction of autonomous robotic systems experts are looking to develop oil and gas facilities that are normally unmanned, with their day-to-day operations controlled by computer programs and intervention managed by robot systems with strategic-level human oversight. At present many robotics experts are focusing on an intermediate state where robots and humans work together.

PETROBOT – INSPECTION FOR CONFINED SPACES AND HAZARDOUS AREAS

Many oil and gas operations involve process vessels and tanks. Maintaining these assets is a potentially dangerous and very expensive task. Shell is working on a project to develop inspection robots for operations in pressurised vessels and tanks.

The Petrobot project is a joint-industry project facilitated by Shell with funding from the European Union (EU). The ultimate aim is to reduce human exposure to the risks of inspection in confined spaces and initial deployment is planned for 2015. Preparing vessels for human entry is expensive and time consuming. Using a robotic system means that in some cases operators can conduct inspections while the storage tank is still full.

Petrobot benefits include reduced costs and time for vessel inspection and reduced entry in confined space for inspection activities.
Making sense of sensing

Shell is working with industry partners, equipment vendors and research teams in the academic sector to develop sensors that can address the challenges of oil and gas operations.
There are essentially two categories of sensor used in the oil and gas industry: those that can provide continuous sensing or monitoring because they are permanently installed or embedded in equipment and those that provide intermittent coverage or inspection-based sensing. This second category includes sensors used by human inspectors, such as hand-held sensors or laser scanners and those installed on robotic devices.

In robotics, sensing has to distinct aims; the first is to give robots capabilities such as sight, touch and hearing that will be crucial for efforts to develop autonomous systems that can navigate their environment and the second is to use the additional sensors, such as ultrasonic testing sensors that enable the robot to perform project tasks. Sensors are also used to provide information about the condition of equipment and plant components in process industries.

Sensors are objects that detect events or changes in their environment, and respond to that change by providing a corresponding output. There are many different types of sensors and various outputs, but in most cases, these outputs will be electrical or optical signals.
SENSORS FOR UPSTREAM APPLICATIONS

In the upstream segment of the oil and gas industry sensors contribute to exploration efforts and help operators manage production at established fields.

In seismic surveys, for example, sensors are used to gather data that guide key exploration decisions such as which locations within a basin are good candidates for an exploration wells. Sensors are also used for other geophysical surveys such as remote hydrocarbon detection, using airborne methane detection and hyperspectral hydrocarbon detection systems to identify hydrocarbon seeps in frontier exploration areas.

Once a reservoir has been developed and entered production, sensors enable engineers to manage production rates by assessing pressure, temperature and well performance data. Sensors can also be used for asset integrity management by providing vital information about the condition of structures and facilities such as offshore platforms or risers.

FIBRE-OPTIC SENSING OF WELL PERFORMANCE

In-well production monitoring can offer crucial insights into hydrocarbon production. Shell installed the world’s first permanent fibre-optic Distributed Acoustic Sensing, in-well production flow monitoring system, in North America.

The system monitors the well through on-demand measurements of flow along the entire well bore, providing a clearer understanding of flow performance from various production and injection zones, without the need for well interventions. Flow reports, sent to the asset team through a secure network, enable operators to optimise oil and gas production.
Usually the oil and gas industry measures the flow and composition of produced hydrocarbon fluids only on high value wells. Typically, flow is assessed using conventional flow meters that are very sensitive, but so expensive to replace that when they malfunction their use is often discontinued. The composition of produced fluids is determined by operator sampling, but this approach is subject to sampling bias and variability. Across the oil and gas industry, high value and high impact decisions are often based on relatively inaccurate flow and sampling information. Shell is addressing this issue with the development of an ultrasonic Doppler velocimetry method that can assess flow rates and compositions in all wells.

**ULTRASONIC DOPPLER VELOCIMETRY**

The Ultrasonic Doppler Velocimeter (UDV) technology have shown the ability to measure interphases in multiphase flows that contain solids/liquid/gas interphases and is able to measure these in non-Newtonian fluids. It is an Ex-situ technique for measuring velocity profile in pipes, reactors, etc. based on measuring Doppler frequency shifts in pulsed ultrasonic sound waves. It is an ‘outside the pipe’ interface meter which provides ‘inside the pipe’ data.

The Doppler effect causes an ambulance siren to sound higher in pitch when it is approaching than when it is receding.

The echoes reflected off the moving ‘particles’ in a multiphase fluid will similarly ‘sound’ different, as the pitch will depend on their speed.

More and more operators are applying techniques for real-time monitoring of upstream operations. Shell is at the forefront of this trend, evaluating a downhole wireless method for real-time monitoring of well operations. The levels of noise, vibration and elevated pressures and temperatures found in oil and gas wells present substantial challenges for reliable sensing.

**DOWNHOLE WIRELESS**

One of the major obstacles to implementing downhole monitoring solutions is the lack of a ‘downhole cloud’ technology that can handle downhole sensor data. Shell is investigating a spectral analysis method for process monitoring. This involves using surface acoustic wave sensors that can capture downhole data and transmit it across the tubing wall to the well annulus.

**SENSORS FOR DOWNSTREAM APPLICATIONS**

Refineries and petrochemical plants are large and technically complex facilities with a requirement for regular inspections to ensure that operations are running smoothly and that they conform to relevant health, safety and environmental protection regulations. In the past inspections were conducted by engineering staff making regular inspection tours of the facility.

In recent years, there has been a shift towards sensor systems that can be monitored from a central control room. This has helped to standardise assessments and minimise the potential for human error during inspection work. In some plants sensors are deployed on robotic systems to minimise the health and safety risks that accompany activities such as working in enclosed spaces.
VESSEL INSPECTION AT NYHAMNA, NORWAY

The Nyhamna gas processing plant in Norway has more than 250 tanks and vessels that must be regularly checked for corrosion or other flaws. Shell has collaborated with designers at Linjebygg Offshore and German firm Wälischmiller Engineering GmbH to develop the Telbot TB 100. This consists of a mechanical arm with a camera that delivers high-quality images and film. The Telbot is programmed with a detailed 3D model of the tank, which it uses to complete the inspection. Footage captured inside the tank is relayed to a control centre where an inspector can remotely assess any flaw. In 2012, the robot inspected four of the larger vessels at Nyhamna, reducing the usual inspection time by almost a week.

The development and construction of a second Telbot robot is nearing completion. In this new system, the components that enter the tank will meet the demanding IECEx Zone 0 standard for locations where an explosive gas atmosphere is present continuously or for long periods. This represents a significant accomplishment for the development team.

EMBEDDED SENSING

Embedded sensors are robust, self-contained systems that are easily embedded in equipment or the process environment. They have the potential to connect all parts of a process chain, revolutionising how it is managed and delivering substantial time and cost savings.

Providing power for embedded sensors is a major issue, especially in situations where there may be hundreds or thousands of sensors distributed across a facility. Most embedded sensors are still battery powered. Technological challenges for the coming decade will focus on automatic recharging of the sensor battery in-situ using heat, pressure, motion, solar power, or other sources.

The sensors must also be rugged – designed for a working lifetime of up to 20 years – and wireless communication will make it easier and more cost effective to install the system in plants, offshore topsides and along pipelines. High-quality embedded sensors are an essential requirement for the industrial Internet of things (IIoT).
**The Industrial Internet of Things VII**

The industrial Internet of things (IIoT) represents an enormous opportunity for the advancement of industrial technology and improvement of process performance. Many global companies are already transforming their infrastructures to take advantage of the emerging potential and to promote adoption of modern Internet technologies in a range of industrial applications. This is enabling engineers to build smart, distributed systems that deliver real-time data and help establish more intelligent and safer operations.

By connecting objects through a digital network, companies will be able to create intelligent systems and applications. This could lead to embedded sensors and software that self-diagnose and self-correct, plus increased reliability as thanks to systems that respond proactively to changes.

**WiSense**

WiSense, integrity monitoring using a wireless sensor network, enables engineers to continuously monitor large areas for missing-metal defects. The method is suitable for complex equipment geometries and requires no surface binding, which makes it easy to install and re-usable. WiSense provides passive measurement of the magnetic field, enabling users to identify and assess corrosion defects that disturb the natural magnetisation of steel.

The sensors are designed for a 20-year lifetime and require no battery replacement or calibration during this period. The low cost and wireless capability of the sensors make them ideal for installation across large facilities including offshore topsides and along pipelines. WiSense can provide 100% coverage of equipment using a dense array of low-cost magnetic sensors that can track changes in a defect over time. The sensors do not have to be in direct contact with the surface, and can therefore be installed above pipe insulation. The system has a wide range of potential corrosion monitoring applications, including general and pitting corrosion, ammonium bisulfide corrosion, localised corrosion, corrosion in non-piggable pipelines and sand erosion.

A high-resolution magnetic scan of a 4-in. pipe with a 1-in x 1-in x 0.06-in external defect (left) and the processed data (right) showing the change in magnetic field caused by the defect.
SENSING FOR PROCESS INTEGRITY MONITORING

Industrial sensors play a key role in process integrity monitoring. In refineries and petrochemical plants, process integrity sensors help to reduce downtime and deferment and to enhance equipment and process safety. Monitoring systems can track temperatures, pressures and flowrates and help operators assess corrosion and erosion defects. However, applying sensor technology across a large site presents substantial technical challenges.

MINIMISING EMISSIONS AT REFINERY FACILITIES

Shell uses an infrared camera system for early detection of gas leaks at its downstream facilities. This technology enables engineers to trace a leak to its source, reduces inspection time, enhances safety and enables the maintenance team to verify the effectiveness of its repairs.

These thermal-imaging cameras are a key element in the preventive maintenance strategy applied at the Shell Nederland Raffinaderij in Pernis (Rotterdam), the largest oil refinery in Europe. Using this technology, each inspector can assess more than 100 objects an hour.

Oil and gas sensor systems have to cope with complex equipment geometries and be both easy to install and re-usable. Shell is working in collaboration with specialist partners to develop a new generation of sensors that will enhance asset management. Our research and development efforts are focused on sensor power, reliability and communication protocols.

DATA PROCESSING AND TECHNICAL CHALLENGES

Shell is working with industry partners, equipment vendors and research teams in the academic sector to develop sensors that can address the challenges of oil and gas operations. For example, sensors that can cope with high temperatures and pressures, and deliver sophisticated downhole capabilities with ultra-low power requirements.

The second issue the industry is facing is scalability – the need to mass-produce low-cost sensors and place them in huge sensor arrays. The third issue is data management. The industry already uses sophisticated algorithms to manage and interpret data, but we will need even better ways to filter and analyse sensor information so we can make better decisions faster.
**STRATEGIC SENSING ALLIANCE**

Collaboration is a cornerstone of many technology developments and, with this in mind, Shell has founded the Strategic Sensing Alliance (SSA). This group will help to stimulate deployment of cross-industry sensing solutions by connecting available technology to industry challenges through a network of technical experts, customers and suppliers.

The SSA is a collaborative space where information can be streamlined to a core network of experts and end users. It includes a comprehensive database of the information that Shell holds and this is open to the external crowdsensing community through a dedicated search tool. The ultimate goal is to make SSA a globally recognised, cross-industry community of experts, suppliers and end users working towards alignment in the future of the IIoT.

The development of SSA has led to Shell’s involvement in several collaborative projects. For example, the recent Downhole Wireless monitoring project. Collaboration will be crucial for the future success of technical developments in the sensing arena. The SSA is currently working with Endress & Hauser, Khrone, MIT, Draper, Texas Instruments, Yokogawa, NASA and others.

**ULTRA LOW POWER NODES**

When operators install large networks of wireless sensors across oil platforms or process plants they must be able to provide power to individual sensors. The sensors can be designed with minimal energy requirements and operated intermittently to minimise power demands and they can make use of a concept known as energy harvesting. Energy harvesting involves deriving energy from external sources, such as solar power, thermal energy, wind energy, salinity gradients or kinetic energy and capturing it for use in small, wireless autonomous devices such as the sensors used in wireless networks. To convert harvested energy into usable power, the wireless sensor node needs a power management device such as a step-down converter.

Shell has experimented with the harvesting of heat energy (thermoharvesting) to prove the concept of clean, sustainable, maintenance-free power for wireless sensor devices. A Shell team used this approach to power a prototype wireless pressure transmitter. The average power consumption of the device was about 2.2 milliwatt and the test set-up worked flawlessly for throughout the two-week field test.
The power of process control

Shell has a long and distinguished history of adopting and benefitting from advanced process control systems.
Automation or automatic control is the use of various systems for operating equipment with minimal or reduced human intervention. In the past automation was usually introduced to save labour costs, but today the focus is more often on saving energy and materials and improving quality, accuracy and precision.

One of the key requirements for successful automation in industrial settings is process control; the engineering discipline that relates to the system architectures, mechanisms and algorithms that manage the performance of a specific process, such as controlling the temperature within a chemical reactor to maintain the volume and quality of product output.

In the refining and petrochemical industries, production control systems automate production processes by monitoring values such as temperature, flow rate, and pressure and then manipulating devices to keep these values at their set points. In some processes, however, it can be difficult to maintain the set range because of factors such as the time lag between device manipulation and resulting changes, and the interaction that occurs when multiple devices are manipulated. Time lag is important as it can lead to instabilities, but in refineries, the relatively slow responses mean that the main problem comes from uncertainties, non-linear behaviours, unmodelled dynamics and insufficient control authority.

The complex processes found in refineries, chemical plants and natural gas liquefaction trains require advanced process control (APC) systems. These systems keep process values within the defined range, while ensuring that they are as close as possible to the optimal set points.

Shell has a long and distinguished history of adopting and benefitting from advanced process control systems.

The previous generation of Shell APC technology the Shell Multivariable Optimising Controller (SMOC) provided the tools necessary to design, implement and maintain multivariable advanced control strategies to effectively improve plant stability and maximise plant profitability. This has been widely adopted around the Shell organisation. This success prompted Shell to develop a new APC that would benefit from recent advances in digital technologies.
The applications developed using PACE enable operators to oversee decisions while reducing the need to participate in every detail of plant operations. This is similar to the situation of a pilot flying an aeroplane in auto pilot mode. Giving the operator an observing role in this manner greatly increases the consistency and reliability of plant performance and reduces the need for human fine-tuning of the control applications.

The key to safe operations is to understand the limits of any process and to operate within them. PACE has models of all the constraints, which makes it possible to stay within the operating window more reliably than a manual operator could. This also helps to reduce stress on equipment as it is being run with smaller variations in factors such as temperature and pressure.

Shell worked with Yokogawa to design and develop a new next generation of APC technology, the Platform for Advanced Control and Estimation (PACE), which was released in June 2015.

PACE will drive down the costs of developing, using and maintaining Advanced Process Control applications while delivering a more consistent and better-optimised process operation via increased throughput, lower energy consumption and/or reduced waste production. Designed to make the various interactions between the user and the software as efficient as possible, PACE will allow assets to design and implement APC applications faster than traditional technologies, while reducing ongoing maintenance activities.

Enabling the more efficient deployment of applications will help operators realise high margin benefits more quickly and reduce project costs. PACE implements new applications faster, monitors optimal performance over a wider range of operations, and reduces downtime. Using PACE, operators can easily deploy applications as part of a control improvement programme.

After each deployment, a post-implementation review includes cost-benefit analysis. In all cases to date, the investment has been paid back in benefits within 6-9 months.
SAFE AND SECURE XII – IT SECURITY IN THE PROCESS CONTROL DOMAIN XIII

Companies that operate major process facilities must be prepared to protect their IT systems against cyber threats such as hackers and computer viruses that have the potential to disrupt operations.

As the oil and gas industry shifts towards unmanned facilities where a remote workforce oversees operations it must rely on major data infrastructure and standard IT solutions. Outsourcing of IT solutions and close integration between industrial and IT infrastructures poses a series of challenges for security. Companies now have to protect networks and facilities that are increasingly remote, dynamic, automated and wirelessly connected.

The process control domain (PCD) contains the IT systems that monitor, control and safeguard production operations. The increased openness of system connectivity and the use of standard IT components and systems in the PCD landscape have reduced costs, enhanced productivity, and raised performance but also introduced new IT security risks. Companies that do not have secure and resilient systems to protect their PCD could face safety issues, unplanned shutdown, reduced production and the potential for reputational damage.

Shell has implemented a PCD IT security programme that delivers secure and resilient systems. This helps operators to achieve process safety and integrity objectives and sustained availability of production and capacity. It can also be used to demonstrate effective controls to support stakeholder/partner confidence and possible regulatory compliance in support of the license to operate.

SecurePlant is being deployed to support facilities including Port Arthur refinery, Texas, USA.

SECUREPLANT

Shell is partnering with IT specialist Cisco on development and support for SecurePlant, an industry-leading technical solution that provides effective IT-security monitoring and management of Shell operating environments. Adopting SecurePlant enables site resources to concentrate on core Shell business and minimises the time and effort they devote to IT infrastructure and compliance activities.

This solution is defined to meet business connectivity requirements and to enable enforcement of and reporting on maturity and compliance, specifically addressing the following practices of the PCD Risk Profile – Asset inventory; access control; operating system security patches; event log management and anti-virus.
The future

A new, leaner industry will take unmanned operations as the standard approach for many plants and production facilities.

Image courtesy of Alstom.
Shell is looking to future developments in robotics, sensing and process control to help deliver an oil and gas industry that is more efficient and safer than today’s technology will allow. A new, leaner industry will take unmanned operations as the standard approach for many plants and production facilities. It will make use of advanced laser scanning methods to design, modify and monitor the condition of equipment such as pressure vessels, tanks and pipelines.

The emergence of systems that use artificial intelligence will accelerate the move towards full plant automation. The use of autonomous vehicles to gather data and to interact with the plant according to carefully defined rules will greatly reduce the need for humans to conduct routine observational tasks. Training and facility planning will be influenced by augmented virtual reality technologies that will give facility operators valuable insights into optimising plant design and safety procedures by tracking how personnel interact with a realistic virtual version of the facility.
**Laser Scanning for Inspection and Monitoring XVI**

Laser scanners enable us to digitise geometrical features of our facilities, providing point cloud representations. They can be used for metrology, for example remotely obtaining measurements of an area that is being prepared for maintenance or new installation. On a much smaller scale, and with appropriate processing, laser scanner data can be used to identify deformations.

**3D Laser-scanning technologies are being used in tank applications, such as inspection, design and modification projects, deformation monitoring, and containment analysis and volume calibration. More efficient and accurate than human inspection, laser scanning also reduces the need for entry to confined spaces.**

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**Unmanned Operations in New Zealand XIV**

Pohokura field is New Zealand’s largest natural gas resource, owned by a joint venture between Shell, Todd Pohokura, and OMV New Zealand. The operational philosophy for the Pohokura production facility was to establish an unmanned site with zero normal operating presence (ZNOP). The plant is operated from an off-site control room using a specially designed Distributed Control System (DCS).

**Artificial Intelligence Makes Its Mark XV**

Many leading companies are exploring the potential of cognitive computing and artificial intelligence (AI) where software learns and applies its new knowledge. Today, Shell uses software from Arria NLG, a London-based group, to monitor its rigs and automatically write safety reports. In the future, artificial intelligence could run a whole range of complex systems, learning under human supervision then operating independently once it has achieved expert status using artificial intelligence and learning algorithms.

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**Laserscanning for Inspection and Monitoring XVI**

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3D laser-scanning technologies are being used in tank applications, such as inspection, design and modification projects, deformation monitoring, and containment analysis and volume calibration. More efficient and accurate than human inspection, laser scanning also reduces the need for entry to confined spaces.
AUTONOMOUS VEHICLES USED TO ASSESS HURRICANE PREDICTION MODELS XVII

Shell is working with the National Oceanic and Atmospheric Administration in the USA to collect environmental data about the Gulf of Mexico. Shell provided autonomous vehicles to test the accuracy of satellite water measurements. During the study, these vehicles created 3,000 ocean heat content profiles that are used to assess how much energy is available to a potential hurricane.

AUGMENTED & VIRTUAL REALITY XVIII

Using augmented and virtual reality, companies can create realistic training environments where staff become familiar with the functions of a plant and emergency responses. A virtual version of the plant, coupled with a process and accident simulator, allows trainees to experience abnormal scenarios. The results of these training exercises may help operators anticipate and reduce potential risks. Augmented reality can also help increase employee efficiency across a range of tasks such as construction activities.

CHIMP

Shell recently sponsored Carnegie Mellon’s CHIMP robot in the recent DARPA challenge to demonstrate advancements in agile robotics and the ability to respond to unplanned situations. Challenges included driving a vehicle, climbing ladders and turning on and off valves. To make unmanned operations a reality, we will need agile robots like CHIMP, with the compute capacity to help make the right decisions on the ground.

In all of its robotic, sensing and process control projects Shell is building on past success to extend the envelope of operations. Effective collaborations are a vital part of our current research programmes as we explore the integrated disciplines that will help deliver the benefits of greater automation. Effective combinations of robotic, sensing and process control technologies could make a huge contribution to the success of future upstream and downstream operations.
INTRODUCTION
A NEW ROLE FOR ROBOTICS
MAKING SENSE OF SENSING
THE POWER OF PROCESS CONTROL
THE FUTURE

ENDNOTES
i  Shell Sustainability-report 2014
ii  Development of robotic inspections for pressure vessels, Martin van den Heuvel Shell Global Solutions, IPTC 6-9 December 2015
iii  Development of robotic inspections for pressure vessels, Martin van den Heuvel Shell Global Solutions, IPTC 6-9 December 2015
iv  petrobotproject.eu/
v  www.optasense.com/2014/09/
op tasense-and-shell-install-worlds-first-permanent-das-production-flow-monitoring-system/
vi  Best practices in meeting oil and gas data acquisition needs
vii  Five Ways the Industrial Internet is Changing the Oil and Gas Industry
ix  Speech by Yuri Sebregts at Sprint Robotics Seminar, Shell Technology Centre, Amsterdam, 23 September 2015 “Shell Perspective on Added Value of Robotics for Inspection and Maintenance”
x  www.mouser.com/pdfdocs/thermal-energy-harvesting.pdf
xi  www.nt.ntnu.no/users/skoge/prost/proceedings/adchem2015/media/papers/0289.pdf
xii  Managing Industrial Cyber Security Risk (Arc Industry Forum 2015 Presentation) Tyler Williams, Manager, Industrial Cyber Security, Shell Global Solutions
xiii  PCD IT security programme, Ambassadors pack, Alice van der Werf and Elena Prill, PCD IT Security Programme Change Management and Communications. TACIT Restricted
xv  www.ft.com/cms/s/0/56b9320e-7af4-11e4-8646-00144feabdc0.html#axzz3nDrXyyh2
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