SPE 112249

Enhanced Awareness of Offshore Teleoperation

C. Skourup, J. Pretlove, N. Stembridge, ABBl; and M. Svenes, StatoilHydro

This paper was prepared for presentation at the 2008 SPE Intelligent Energy Conference and Exhibition held in Amsterdam, The Netherlands, 25–27 February 2008.

Abstract

The major challenges for future oil & gas installations are to create and increase business value in addition to improve HSE (Health, Safety and the Environment). The Oil & Gas industry has recognised the potential of operating with 'normally unmanned areas' where access to the entire process is based on utilisation of new technologies from remote onshore locations. During maintenance, personnel have only got restricted access when the process is shut-down, but this is primarily handled remotely. This paper concerns teleoperation and telepresence of oil & gas installations. The challenges involve more than the technology of transferring data and performing operations. A teleoperator or a telerobot is a “machine” which extends a human operator's sensing and manipulation capability to a remote environment. An essential issue of telepresence is to keep the human operators in the control loop to enable them to use their high levels of skill to complement the power of remote manipulators. Teleoperation within oil & gas differs from other known applications as offshore installations represent large, complex and dynamic processes located hundreds of miles away in very harsh environments where failures may result in major consequences for the environment and process equipment.

The challenges of offshore teleoperation are to enhance the operator's perception of the current situation so that the operator has a complete understanding of state of the process and operates the process as if he was offshore without hundreds of miles and complex technology in between. Safe and efficient teleoperation is critical for operation of unmanned platforms to secure added value and optimal production within a distant environment.

Introduction

Oil & gas companies continuously seek to create and increase business value of oil & gas installations. Particularly the increasing energy consumption on a worldwide basis and, as a result, the substantial increase of the prices is major drivers for expanding exploration and exploitation. Oil & gas production is an activity with an increased complexity due to a gradual transition to tail end production. Many of today’s oil & gas fields are approaching the maximum limit of what has technically been possible to extract based on existing solutions. These installations were not designed and constructed to last as long as until today when established. However, the current push in technology together with the high demand on energy and the high oil prices represent significant drivers to develop new technologies to extend the life time of existing installations. Meanwhile the search activities for new oil & gas reserves are intense as well as the focus on R&D to develop novel technological solutions to be able to extract oil & gas from the grounds where it was not possible even a few years ago. A substantial number of new reservoirs are located in harsh environments and areas with ongoing conflicts which put additional demands on new installations and technology. The oil companies face an increased need for reducing costs and boosting productivity.

Altogether, three outstanding goals for designing and operating offshore installations whether it is existing or future facilities are to:

- Improve Health, Safety and Environment (HSE)
- Reduce CAPEX (capital expenditures)
- Reduce OPEX (operational expenditures)

The oil & gas industry do have a very strong focus on HSE. Operation and maintenance of an offshore installation is a risky task particularly as it involves people. The goal is to continuously reduce the risk of injuries, incidents and accidents particularly for people and hence to improve HSE. Additionally, designing, commissioning, operating, maintaining and/or decommissioning oil & gas installations represent high costs, which the oil & gas industry continuously strive to reduce to optimize the return on investment (ROI).

To address these issues, a major rethink on the conventional operation and support of oil & gas installations is required. It is therefore proposed to implement robotics technology on new offshore installations together with a redesign of the process equipment into compact standardised process modules. Utilisation of robotics within Oil & Gas is not new itself, but has until now been limited to special functions such as subsea and pipeline inspections (Remotely Operated Vehicles, Pigs, etc), automation of drilling operations, well tractors and special applications for inspection purposes. It is well documented that industrial robots with flexible manipulators are well suited to conduct dangerous and labour intensive tasks in hazardous environments with a high degree of accuracy. This novel concept will result in a remotely operated oil & gas facility capable of conducting inspection, maintenance and normal operational tasks. It is obvious that HSE issues related to humans will be reduced to a minimum as people are basically removed from the platform. As a consequence, the need for living facilities for offshore staff will be reduced radically, which means lower weight of the platform and hence, less CAPEX. Further, this technological solution has the potential to reduce OPEX, thus increasing the profitable lifetime of the facility.

The focus of this paper is on teleoperation and telepresence of oil & gas installations. Teleoperation within oil & gas differs from other known applications as offshore installations represent large, complex and dynamic processes located hundreds of miles away in very harsh environments where failures may result in major consequences for the environment and process equipment. The challenges of remote operation involve more than transferring data and performing operations. An essential issue of telepresence is to keep the human operators in the control loop to enable them to use their high levels of skill to complement the power of remote manipulators.

Therefore, the challenges of offshore teleoperation are to enhance the operator's perception of the current situation so that the operator has a complete understanding of the current process state and operates the process as if he was offshore without hundreds of miles and complex technology in between.

This paper presents the concept of the Facilities for the Future aiming at the remotely located operator, his demands and collaboration with technology. Intelligent instrumentation and sensors will be the 'eyes and ears' of the remotely located operator and the robot manipulators will perform as the "hands" of the operator. Together they perform as a telerobot. Particularly, the operator will need enhanced situation awareness of a remotely located process. This paper discusses the situation awareness and the importance of efficient collaboration between the human operator and the automation system in order to perform safely.

Vision of Integrated Operations

The challenging demands and goals within the oil & gas segment lead to a genuine interest and flexibility in the organizations. Collaboration is recognised as essential to achieve efficient and safe operation of industrial processes such as power, process, utilities and oil & gas industries. In many cases, the collaboration takes place over a distance, for example, between the control room and a remotely located expert or a field operator. Currently, a shift in the organizational structure is taking place towards the philosophy of Integrated Operations (IO). Integrated operations is an effort to achieve goals based on a combination of new methods, the latest development in technology and work processes. StatoilHydro defines integrated operations as "collaboration across disciplines, companies, organizational and geographical boundaries, made possible by real-time data and new work processes, in order to reach safer and better decisions – faster." A result of integrated operations is large onshore operation centres with the goal to increase safety, to reduce costs and to profits through increased collaboration and better decisions. The point is to make real-time data available anywhere and to support this extended data access with work processes for optimal operation. The focus on HSE is essential in order to succeed with integrated operations. Some organizations are already undergoing radical changes towards virtual distributed decision making teams. The trend is to have operational staff onshore to support and collaborate with offshore personnel. Distributed, multidisciplinary teams work in parallel on real-time data. The physical location is irrelevant as technology supports collaboration in a virtual space. Another significant issue is that integrated operations are proactive instead of reactive. Hence, there is a strong focus on handling situations before they develop into critical situations, which may result in production loss, or to perform maintenance when needed instead of periodically.

However, there is also a risk involved when changing the organisational structure so that it to a larger degree depends on efficient collaborations between actors situated at different physical locations. One key issue that has been identified is the need for common situational knowledge between the different actors (Johnsen, et al., 2005).

The Facilities for the Future concept is based on the integrated operations philosophy. Given the importance and focus of cost, safety and environmental issues in the Oil & Gas industry today, such new solutions based on normally unmanned installations with remote control from onshore operation centres, combined with more extensive use of robotics technology, are highly relevant. The Oil & Gas industry has recognised the potential of operating with 'normally unmanned areas' where access to the entire process is based on utilization of new technologies from remote onshore locations. During maintenance, personnel have only got restricted access when the process is shut-down, but this is primarily handled remotely. These future facilities are divided into two zones; a normally unmanned zone and a normally manned zone. The former contains the process modules itself whereas the latter is a zone including living facilities with low capacity. The technology is in place today to provide remotely located staff with real-time data from the process. But there are other challenges of operating remotely; today's operators are highly dependent on physically presence in the process. Field operators are the "eyes and ears" of the control room operators and are very good at sensing process changes which the instrumentation has not necessarily detected or may not even be able to detect. Safe and efficient teleoperation is critical for operation of normally unmanned processes to secure added value and optimal production within a distant environment and requires enhanced process awareness.

In the Facilities for the Future concept, the remotely located operators together with the automation system will have to take over the tasks and responsibiltities of the field operators as offshore staff is moved away from the platform. In addition to the operational tasks, the operators have to perform inspection, maintenance and intervention tasks. These tasks raise new challenges to be solved. Other processes such as nuclear power plants are already teleoperated and experience can successfully be gained from these. There are however differences such as the harsh environment and the distance between the onshore operation centre and the offshore installation. The future oil & gas facilities concept is based on a complete redesign of the process into standardized compact process modules. Robot manipulators mounted on gantry cranes will act as the field operators' "hands" and perform inspection tasks, light maintenance tasks and intervention tasks. The process will be equipped with intelligent instrumentation which, together with sensors carried by the robot manipulators, will make up the operators' "eyes and ears" in the process. The automation system comprising the robot manipulators and the intelligent instrumentation can (relatively) easy perform predictive routine tasks. The challenge lies in unpredictable situations and the human's ability to perceive an advanced spectre of information input and to identify even small changes from the normal state. In the future facilities, the onshore operators will need a support system to have the process awareness.

Challenges and relevant issues of teleoperation

A teleoperator or a telerobot is a machine or device which extends an operator's sensing and manipulation capability to a remote environment. A telerobot is an advanced form of the teleoperator. The human operator supervises its behaviour through a computer. The telerobot executes the task on the basis of information received from the human operator in addition to its own artificial sensing and intelligence (Sheridan, 1992). The history of such devices as known today can be traced to late 1940s and early 1950s where they were developed by the nuclear industry for use in "hot cells". Today modern and advanced teleoperators and telerobotic devices are finding numerous application areas in hazardous and remote environments. These systems consist of sensors and manipulators placed in the hazardous environment connected to displays and controls that the human interacts with.

To operate effectively in the remote environment the operator requires sufficient 'presence' to be able to interpret the remote scene and undertake the task effectively and efficiently and this is usually accomplished by using a telepresence system. A telepresence system displays high quality visual information about the task environment and in such a natural way that the operator feels physically present at the remote site. The challenges that lie ahead call on a multidisciplinary approach to develop the interface between man and machine and relies on studies of human perception and cognition as much as by control and engineering considerations.

Human in the loop

Keeping the human operator in the control loop in telerobotic devices is a significant advantage because it enables them to use their high levels of skill to complement the power of the remote manipulator. This approach makes considerable sense: humans are good at making judgements, understanding tasks, recognising objects (even in complex and cluttered scenes), reasoning, problem solving and being creative. Computers on the other hand are very good at storing and searching vast amounts of data, repeating routine tasks and multi-tasking.

Research activities are focusing on the three principal and independent determinants of the sense of presence in a remote environment. These are the extent of sensory information (ideally the same level of sensor information that the operator would have if they were physically in the remote environment), the control of the sensors (the ability to modify the position of the sensing device) and an ability to modify the remote environment (to be able to change objects in the remote environment or their relationship to one another). The success of this approach is due, in part, to visual capture, which is the tendency to believe the eyes above all other senses, and to the concept that humans reconstruct and understand their environment by active exploration rather than by viewing static scenes. It also allows the operator to fully concentrate on the task in progress rather than to spend time on manipulating the cameras to provide the best view. To perform what the human is best at, the operators have to be aware of the current situation at any time. They need the "right" information at the "right" time to be able to understand the current situation and to make the "right" decision.

Applications

Teleoperators and telerobots are used in a wide range of application areas. The space and military industry represent significant driving forces behind the development of teleoperation and telerobotics. Many of the state-of-the-art solutions can be found within these areas. Other important fields are within the oil and gas industry for subsea intervention, search and rescue as well as within medical, typical in minimal invasive surgery and telesurgery.

All space activities rely on telerobots, most with relatively simple control strategies, low bandwidth capability to transmit and receive images and control data and the ability to be reprogrammed in space. There are a number of applications in the military field for telerobotics ranging from Remotely Operated Vehicles (ROV) to Unmanned Air Vehicles (UAV) and teleoperated ground vehicles. Modern UAVs like US Air Force Predator are remotely piloted by radio or satellite links. They can also have the capability to fly autonomously with the help of GPS and inertial navigation. Their typical tasks are reconnaissance and target identification. Unmanned Ground Vehicles (UGV) have a wide application field in military operations. Typical tasks are reconnaissance, surveillance, target acquisition, route clearing, ordnance disposal and landmine detection. The first UGVs were fully teleoperated with closed loop control. The newest models are equipped with vehicle localization (GPS, Inertial navigation) and supervisory control to improve the performance. Military UGVs are often supplied with the state of the art teleoperation equipment like stereovision telepresence etc. to provide best possible feedback in fast and dangerous operations.

Subsea applications include deep-sea exploration, inspection and maintenance, geological surveys and search and recovery. Remote Operated Vehicles (ROV) are suitable for these very harsh operating environments and are often equipped with telemanipulators to perform underwater manipulation tasks. ROVs are generally tethered to a surface ship and controlled using video monitors and joysticks. The most recent system can also perform some autonomous tasks such as station keeping or track following. Medicine is a relatively new field, but there is a considerable and increasing interest in telerobotics and teleoperation. Medical imaging such as CAT and MRI is now being used to guide robotic devices to assist surgeons. There is a good deal of experience in using these systems for improving the consistency and quality particularly of prosthetic joint implants, guiding abdominal laparoscopy and neurosurgery. Also telesurgery, where the expert surgeon is not co-located with the patient, is a challenging application with considerably high requirements on technical issues such as bandwidth to secure safety first and foremost for the patient.

State of the art and principal technical challenges

Control Schemes

The degree of automation for a telerobotics system ranges from entirely manual control to fully automatic. In manual control, the operator performs the task using the manipulator as a tool with no intelligence. Fully automatic is when the control system runs automatically without any need for intervention from the operator. Often, the automation level of a telerobotics system varies regarding the tasks, also within on specific task.

Some remote manipulators can be very slow to respond because of their high inertia, or imposed limits on the acceleration of the manipulator, while in other systems the operator has to adopt a move-and-wait strategy because of long time delay. Manual control of the remote manipulator in such cases can be tedious if carried out for long periods of time, as the operator is continuously in the control loop. Such continuous involvement in the task can also prevent the operator from doing other tasks, such as planning the next manipulation step. The manual control of remote manipulators requires sufficient training, before the operator becomes familiar with the dynamics of the system but with substantial training this control regime is suitable for quite complex tasks.

Supervisory control is a mixture of manual control and autonomous control, where the autonomous operations are performed under human supervision. The control loop is partially closed between the robot sensing and actuation at the remote site by an intermediary computer. The intermediary computer executes the lower level tasks based on higher level instructions from the operator, who plans the task and teaches the intermediary computer at a level of detail which the remote computer can execute autonomously. The task is monitored during execution and the operator intervenes if execution deviates from the original plan, even to the extent of assuming direct control over the low level functions.

Supervisory control is well known in teleoperation and was initially proposed in 1967 for overcoming the time delay effect in space operations. Supervisory control means that one or more human operators intermittently program and continually receive information from a computer that itself closes an autonomous control loop through artificial effectors and sensors to the controlled process or task environment. The level of supervision depends on the involvement of the human operator and the sophistication of the computer autonomy.

One method of achieving supervisory control in teleoperation is shared control, or dynamic task allocation, which is based on sharing the task instructions between manual and autonomous control, such that each complements the deficiency of the other and tasks can be interchanged dynamically. A two tiered structure for shared control is often described, consisting of an execution level which is handled autonomously and a task sharing level. The task sharing level receives inputs from both the autonomous procedures and the operator, and gives outputs to the execution level, by checking the consistency of the operator's commands with the autonomous procedure. The main issue in shared control is to decide which task should be assigned to humans and which to computers.

In some systems which have comparatively higher level of autonomy, the operator can roughly position the manipulator near the object with which the end-effector has to be aligned and the manipulator aligns itself with the object automatically. Such a capability requires automatic recognition of the aligned object by machine vision techniques and determination of its location. The object recognition is done by matching the object image with a previously known template of that object. In other systems, if all the objects in the task space are known, the manipulator can navigate through obstacles to reach the destination position automatically. All of these higher levels of autonomy depend on an ability to understand the environment, which in turn depends on the knowledge of the structure of the environment.

Response time

Continuous manual control of the remote manipulator is impeded if there is a time delay between the control input by the operator and the consequent feedback of its control actions visible on the display. When a human operator is in the control loop, potential system instabilities can be avoided by using a "move and wait strategy", where the operator makes small incremental moves in an open loop fashion and then waits for a new update of the position of the telerobot.

A time delay in communication between local and remote site can occur due to a large distance between them, to a low speed of data transmission or to computer processing at different stages. For space telerobotics a round trip time delay of up to

6 seconds is not uncommon and deep sea delays are of the order of 10 seconds. Apart from the speed of communication and distance, considerable time can be taken by signal processing and data storage in buffers at various stages between the local site and the remote site. Non-deterministic communication channels such as the internet cause additional problems due to added uncertainty in the actual magnitude of the time delay.

Video signals are the most difficult to transmit due to the requirement of a very high bandwidth. A lower bandwidth will necessitate the drop of either rate at which the display is updated (frame rate), the resolution of the display or the number of levels of brightness (gray scale) available at the display. In general operator performance has been shown to be adversely affected by decreases in the frame rate, resolution and colour depth.

Human-machine interaction

The quality of the system and its ability to achieve the task depends, to a large degree, on the performance of the operator who must be able to perceive, understand and execute the task. The telepresence system provides sensing and display technology to enable the operator to “feel” present at the remote location even though not really there.

One of the difficult problems in visual displays for teleoperation is the presentation of three dimensional relationships at the remote site on a two dimensional display. Most of the reported teleoperation systems with a human operator directly in the control loop use video displays, which range in sophistication from monochrome monoscopic systems to (immersive of projected) colour stereoscopic video displays. Also artificially generated graphical displays have been used to enhance depth perception for teleoperation.

Transmitting camera images or video from the remote location to the operator is one method of presenting information about system status. There are several options for such cameras: stationary, fixed point with zoom/pan/tilt, mobile cameras and stereoscopic cameras. Fixed mount cameras are simple to use, simple to install and cheap. No moving parts also mean that they are less prone to fault and can be environmentally hardened. However, the functionality is also reduced and is best suited when the area or object to monitor can be sufficiently viewed from one position.

More mobility and flexibility for the video images is achieved by fixing the cameras to movable robots or to controllable pan and tilt platforms. This can be done by attaching the cameras to the operating robots themselves, or by using dedicated robots that can be controlled separately to give the best possible angles and positions for overview and detail video images. The military sector has used remotely operated vehicles/robots for camera inspection with great success. Stereoscopic cameras provide two separate video streams that can be used for true 3D image visualization. The Facilities for the Future concept utilizes robot manipulators to carry cameras around in the process for different inspection. The success of a visual telepresence system relies on two characteristics: sufficient visual information relayed to the operator to enable him to interpret the scene and an ability to (intuitively) control the gaze position of the remote cameras.

Visualisation

Most teleoperation tasks are carried out in three dimensions and require that the operator has a good mental model of the task and the processes. Visualising the task can be challenging with only a monoscopic view because of the lack of depth information although for certain tasks and with familiarity a good deal can be inferred from other visual cues such as light and shadow, linear perspective and size constancy of familiar objects. The effect this has on performance is largely dependent on the familiarity of the viewer with the objects. In the presence of only monoscopic cues, misperception of scenes with unfamiliar objects, backgrounds or movements can occur and depth judgement can be severely impaired.

Stereoscopic video provides additional binocular cues, which help in depth display and increased realism in the display of a remote site. To display stereoscopic video, the inputs from two video cameras placed at the remote site, which correspond to the two eyes of the operator, are combined and presented to the operator on a single display, such that the input from each camera is presented to its corresponding eye.

Three-dimensional visualization techniques are better suited for presenting high-quality information about the geographical and spatial aspects of a situation. By presenting a 3D model that corresponds accurately to the object or area at hand, the operator can have much better situational awareness and understand potential problems and their solutions quickly. It also enables geographically separated domain experts to work on a common model.

The interface to telerobotic and telepresence systems can be greatly extended and enhanced by overlaying computer generated graphics onto the images that are coming from the remote environment. This concept of combining computer generated graphics with a video signal is called augmented reality (AR) and the operator sees the real world with virtual objects superimposed upon it. In this way augmented reality supplements the real world rather than replacing it and, if it is successful, the real and the virtual should co-exist so that the user cannot easily distinguish between the two. It is anticipated that this will reduce the information burden placed on operators while improving the situation awareness, quality and integrity and speed up the production process. Augmented reality can be used to present information not otherwise available to the operator, enable interaction with real world objects or provide contextual information to the operators.

Control input devices

Using traditional input devices such as mouse and keyboard for advanced visualization systems is often insufficient. 3D systems particularly require advanced input devices as the information space is three-dimensional as opposed to the two dimensions of the mouse. In spite of the advances in mouse interaction for 3D environments – mainly brought forward by the gaming industry – there is a need to enhance the user interaction methods by developing and utilizing novel and intuitive input devices. Numerous studies have been conducted to investigate the usefulness of force feedback in remote control and these studies show varying degrees of success. It is clear that the importance of haptic and force feedback is task dependent and not appropriate in the presence of large time delays where is can cause system instability.

Joysticks are used for remote control within military and medical industries as well as within the gaming industry. This is well proven technology that is easy to understand and learn. Recent joysticks have a number of buttons for additional input commands as well as vibration and force feedback.

The CAD and 3D modeling communities have developed various desktop mice that have extra degrees of freedom (up to six) compare to traditional 2D mice. These mice are more efficient for navigation three-dimensional environments and often have a number of buttons for additional command inputs. Another type of 3D mouse are those that are “free flying”, where the position in space is one of the input signals from the input device.

Gesture recognition is another method for entering control inputs. This can be done by tracking body posture and body parts and assigning commands to certain gestures. For example, if both hands are tracked by a position sensor, pointing in one direction might indicate flipping the page in that direction when reading an electronic document.

Using eye movement directly as input to a computer system becomes more and more relevant as the technology matures. These systems are among others used for testing usability of web page design, psychological evaluation and computer interaction for people with physical disabilities.

Theories on situational awareness

In future oil & gas facilities, fewer remotely located operators need to run more complex system with increasingly higher efficiency. The single-most outstanding difference of the situation as of today is that the operators are moved away from the process and have to teleoperate on the process using robot manipulators in combination with intelligent sensors and instrumentation to achieve the presence of the process. To meet these ‘new’ and increasing demands, the interface between the human operator and the technical process really has to support the human both by presenting information and by being able to take inputs from the user into the system in an efficient way. The human-machine interaction has to be developed to support the human – in what the human is good at – to secure that information is easily comprehensible and to reduce the risk of misinterpretation of such valuable information.

With this in mind, a correct understanding of the behaviour and status of the process is essential to achieve efficient operation and for taking correct actions when needed. Also, collaboration with co-workers in order to communicate and discuss aspects of the process is principally based on a common process perception to avoid misapprehensions and errors between the humans. Altogether, to be able to make decisions regarding new (and unexpected) situations requires a correct mental model of the process and the environment, which may influence the process (Johnson-Laird, 1983). Endsley’s model of situation awareness describes three different levels that are essential for successful decision making in complex, dynamic processes (Endsley, 1995).

In order to make optimal decisions, the operator needs to understand the current situation of the process. Decision making is a complex and hard human process where operators continuously have to be aware of and understand both the current process state and new states, and to plan for actions to avoid unwanted situations. The individual mental model provides the operator with a general understanding of the process. The focus of Endsley’s situation awareness model takes this further and describes how people in complex, dynamic systems make decisions, which information they have available and how they interpret such information (Endsley, 1995). The model consists of three levels:

- The perception of elements in the environment within a volume of time and space
- The comprehension of their meaning
- The projection of their status in the near future

The first level describes how humans perceive information elements in the environment that either deviate from the original situation or represent a state, which contributes to a description of the current process state, or situation. These elements trigger the operator’s consciousness that something is deviating. At the second level, the person gets a deeper understanding of the current situation while still actively searching for additional and complementary information. Finally, the person uses his mental model to simulate potential actions based on perceived information and the present interpretation and understanding of the specific information. When the operator is satisfied with the internal “simulation” of these actions, the decision regarding which ctions to perform naturally takes place. At all levels, internal and external factors may influence the decision making process. Internal factors refer to the person’s age, background, competencies and mood whereas external factors may be organizational goals, directives and procedures.

The operators’ situation awareness is very critical for operating the industrial processes successfully. When considering the interaction between the industrial process and the operator, essential issues concerns what may go wrong, where it may go wrong and why it goes wrong. According to the model, errors occur either due to incomplete situation awareness or inaccurate situation awareness.

Collaboration between operator and automation system

In the early days of industrial automation, system designers attempted to automate everything and remove the human operator – whom they considered the weakest link in the process control loop – entirely. When this approach failed, the human was assigned tasks the designer was unable to automate. The trend nowadays is for substantial human involvement rather than to eliminate people in industrial process automation (Pretlove & Skourup, 2007). For the Facilities for the Future, the extended collaboration between the operators and the automation system as a telerobotics system changes the focus from human-machine interaction to human-machine collaboration.

Miller & Parasuraman (2007) suggest that the next step to further improve the human-automation performance is to assign the overall responsibility for the supervisory control system to the operator. This is not to be confused with the operational or organisational responsibility, but concerns the allocation of roles and tasks between the operator and the automation system. As peers, the operator and the automation system have to perform like two persons working together where one person is responsible and the other contribute to perform the various tasks. Ideally, all their cognitive tasks should be based on equal mental models. This is however not likely to be the case, but different technological solutions can support harmonisation of the various mental models. The operator will particularly need continuous feedback from the automation system on which tasks the system performs and performance of these tasks in addition to being the "only" interface towards the process.

The responsibility of task allocation implies extensive skills in, for example, decision making, reasoning and judgement, which are some of the human strengths. These all represent processing at the knowledge-based level of behaviour according to Rasmussen's SRK model (Rasmussen, 1985). Therefore, this model also supports the concept of the supervisory control system where the operator has the role of performing such high level tasks in contrast to the automation system. Human decision making in dynamic and complex processes is absolutely dependent on a satisfactory understanding of the current situation and a good mental model of the process and the automation system (Endsley, 1995). Information inputs trigger a mental model on which the operator bases further gathering of information to understand the current situation and finally, simulates and predicts the results of potential decisions.

In addition to a comprehensive understanding of the processes and the current state of the process, other premises are an extensive network of accessible experts and trust in the automation system. Increased responsibility may influence the level of stress. Also, the fact that the number of operators is reduced at many facilities may represent a mental stress factor and hence, have an influence on the performance. Some operators already perceive their workload as high. Therefore, virtual collaboration spaces which are a natural outcome of integrated operations within the oil & gas industry represent a pool of knowledgeable resources that are always available. Similar as to the collaboration between the operator and the automation system, the importance of a common understanding of the process and problems is vital to decrease the stress factor of extended responsibility.

Finally, it is decisive that the operator finds the automation system trustworthy, which is fundamental for all collaboration. Studies of collaboration between humans show that people allocate tasks dynamically without having a clear plan in advance of who is doing what. Adapting a similar concept to the collaboration between the human operator and the automation system assumes that the operators trust the automation system. It is challenging just to reach an acceptable level of trust for an ordinary automation system where task allocation is defined properly in advance. New challenges arise when task allocation becomes dynamic.

Adaptive and augmented situational awareness

It is apparent that the operator needs extended support to perform his new responsibility of allocating tasks within the supervisory system. The conventional user interfaces for process control based on P&IDs (Piping & Instrumentation Diagram) have remained the same over many years partly due to safety critical systems and the lack of user involvement during system design. Through these interfaces, the operator perceives large amounts of information from a number of very different information systems, often not integrated. Besides, there is no doubt that there are situations where operators often perform on the edge of their mental capacity. Therefore additional information needs to a higher degree to be adapted to the operator's current tasks and mental condition such as level of stress. Such context-related background information is not just relevant for presentation of process and situation related information, but also for decision support from such as to provide recommendations on task allocation between the operator and the automation system, which should substantially depend on the operator's situation and condition. The challenge lies in presenting, integrating and/or adapting information in a knowledgeable way so that additional information still means less information, or at least not more, to perceive and comprehend.

Conclusions

The concept of the Facilities for the Future has a high potential to improve Health, Safety and Environment (HSE) as the process area will become normally unmanned. As a consequence, the need for enhanced operator awareness in order for the remotely located operator to perform efficiently will be one of the main tasks of the telerobotics system. Intelligent instrumentation will function as the operator's "eyes & ears" in the process even though located hundreds of miles away. Similarly, robot manipulators will take the roles as the operator's "hands"as well as "eyes & ears" as the robots will also be able to carry sensors around in the process directed by the operator. The main tasks of the robot manipulators will be to perform inspection tasks, light maintenance tasks and intervention tasks. The automation system will initiate some of these tasks automatically such as predefined and periodically inspection tasks whereas the operator will have to intervene when unpredictable situations occur. The operator will still utilize the advanced automation system to perform regularly monitoring of the process equipment strongly supported by input from various sensors. Cameras will play a significant role together with 3D models of the facilities. In addition, other sensor output may complement the video images of the process.

The Facilities for the Future concept gives integrated operations a new dimension; extended collaboration between the human operator and the automation system where the offshore telerobot will substitute today's field operator as these facilities become normally unmanned. The telerobot becomes a new member of the integrated operation team with a special emphasis on enhancing the process awareness.

Acknowledgement

This project is a collaborative project between StatoilHydro and the consortium consisting of ABB, IBM, SKF and Aker Kvaerner. We would very much like to thank all the partners who all make it possible to achieve goals which would not be possible otherwise. Also, we would like to thank the Norwegian Research Council who supports this project with additional funding.

References

Bainbridge, L. (1983). Ironies of automation. Automatica, 19 (6), 775-779.

Endsley, M. R. (1995). Towards a theory of situation awareness in dynamic systems. Human Factors, 37 (1), 32-64.

Johnsen, S. O., Lundteigen, M. A., Fartum, H. and Monsen, J. (2005). Identification and reduction of risks in remote operations of offshore oil and gas installation, Esrel 2005-01-10, Poland, 27-30.

Johnson-Laird, P. N. (1983). Mental models: Towards a cognitive science of language, inference, and consciousness. Cambridge, MA: Harvard University Press.

Miller, C. A. & Parasuraman, R. (2007). Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control. Human Factors, 49 (2), 57-75.

Pretlove, J. & Skourup, C. (2007). Human in the loop. ABB Review, 1, 6-10.

Rasmussen, J. (1983). Skills, rules, and knowledge; Signals, signs, and symbols, and other dis-tinctions in human performance models. IEEE Transaction on Systems, Man, and Cyber-netics, SMC 13, 257-266.

Sheridan, T. B. (1992). Telerobotics, automation, and human supervisory control. Cambridge: The MIT Press.

Skourup, C. & Pretlove, J. (2005). Improved situation awareness with augmented reality. In G. Salvendy (ed), Human Computer International 2005 (CD), US: Lawrence Earlbaum Asso-ciates Inc.