Advances in Remote Monitoring Technology for Worker Safety and Personnel Radiation Exposure Reduction – 15130

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ABSTRACT

This paper will present an overview of advancements made in remote monitoring technology to increase worker safety and decrease personnel radiation exposure at hazardous work sites. The presentation will discuss the use of remote technology for risk reduction to working parties. Topics covered will be the use of technology as a human performance tool in pre and post job briefings, scheduling tool for work management and communication tool between working parties and radiation protection personnel that allow for micromanaging radiation exposure. The presentation will use actual technology field experience to illustrate best practices within the commercial nuclear industry and there applicability to the waste management sector.

ACRONYM

BICS – Brooks In-bundle Camera System

CCD – Charge-couple device

CMOS – Complementary metal–oxide–semiconductor

HVAC – Heating, ventilating, and air conditioning

FCM – Fuel containing material

ECT – Eddy Current Testing

FOSAR – Foreign Object Search and Retrieval services

ICH-4 – Rolls-Royce Integrated Camera Head – 4

LAN – Local area network

NVMS – Mobile Network Video Management System Solution

OCC – Outage Control Centers

RAD – Radiation absorbed dose

RCP – Reactor Coolant Pump

REM – Roentgen equivalent man

ROV – Remotely Operated Vehicle(s)

RP – Radiation Protection technician

SWATS – Shell Wrapper Transport System

SROV – Submersible Remotely Operated Vehicle(s)

UAV – Unmanned Aerial Vehicle(s)

UT – Ultrasonic testing

WAN – Wide area network

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CONCLUSIONS

Remote monitoring technology is a key element in increasing worker safety and decrease personnel radiation exposure at hazardous work sites. Remote equipment can collect data and samples from areas that would be impossible for humans to enter.

The technology exists today to remotely monitor hazardous areas. Before planning work in these areas, remote technology solutions must be evaluated to ensure worker safety.

INTRODUCTION

Remote monitoring technology has been in use for decades as a way to perform critical tasks in areas that are hazardous to workers or areas that do not provide access by humans due to spatial constraints. Examples of hazardous areas include confined spaces, high radiation areas, and areas with chemical, radioactive or biological contamination. Examples of spatially constrained areas include inside pipework, HVAC ductwork, tanks, turbines, heat exchangers and pumps. While these solutions commonly solve these complex issues, special consideration should be taken to make sure the technology is well matched with the application.

This paper will look at the benefits, special considerations, typical applications and some cost benefit examples.

Remote Technology

Remote technology can take many forms, from simple camera systems for observation to sophisticated robotic delivery platforms capable of performing precision services. The most common purposes behind using this technology are dose reduction and access to areas too confined or dangerous for workers.

Remote camera technology falls into two basic categories, remote monitoring and remote visual inspection.

Remote Monitoring Systems

Remote monitoring systems for the nuclear industry were originally developed to view critical processes in high radiation areas from a safe location. Video cameras based on older vacuum tube technology were identified as fairly resistant to damage from radiation, in particular Newvicon and Vidicon types. These cameras were primarily monochrome and had several shortcomings such as size, weight, high operating temperature and burn in that restricted their use to limited applications, however, the resolution was typically very good.

As technology evolved, “tube” cameras used for surveillance gave way to solid state designs starting with CCD and in time the newer CMOS devices. Eventually, mainstream tube camera production virtually ceased and became a low volume and high priced option. Today, most cameras used for remote monitoring are CCD or CMOS due to their lower cost and proven benefits, unless the application requires a more radiation tolerant device.

Fig. 1 – ICH-4 Camera & Local Power Supply utilizing quick connect pole mount

Fig. 2 – ICH-4 camera

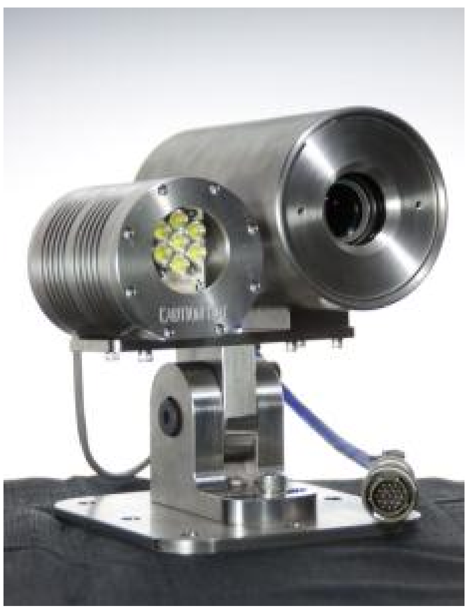

Fig. 3 – RCP Monitoring Camera System

Fig. 4 – CDS-5000 Mini IP Dome Camera System with Quick Connect pole mount

Fig. 5 – High radiation camera example

In applications where CCD or CMOS devices do not provide an acceptable level of radiation tolerance, which is typically 1 x 10^4 rads total dose gamma, tube cameras are still an option although, the production levels are very low which drives prices up and availability down. There are other technologies available such as CID technology that use solid state components and provide image quality features minimum radiation tolerance of at least 1 x 10^6 rads total dose gamma (1 MegaRAD) total dose. In either case, the radiation tolerance of the optics between the camera sensor and the object need to be considered. Generally speaking, certain elements of glass tend to darken in the presence of high radiation levels. In very high radiation applications, “non-browning” lenses must be used. These lenses are made using cerium oxide doped glass or synthetic silica, enabling them to withstand radiation doses of up to 1 x 10^8 rads without discoloration or degradation of performance.

In the last five years, control and video from the camera has become much simpler to incorporate into site infrastructure with the development of network video platforms. This platform allows a much higher degree of flexibility because the systems can be run off the existing site LAN as opposed to dedicated copper or fiber infrastructure. State of the art systems can easily distribute the video from any of the camera locations to any user on the LAN, WAN or web based user points.

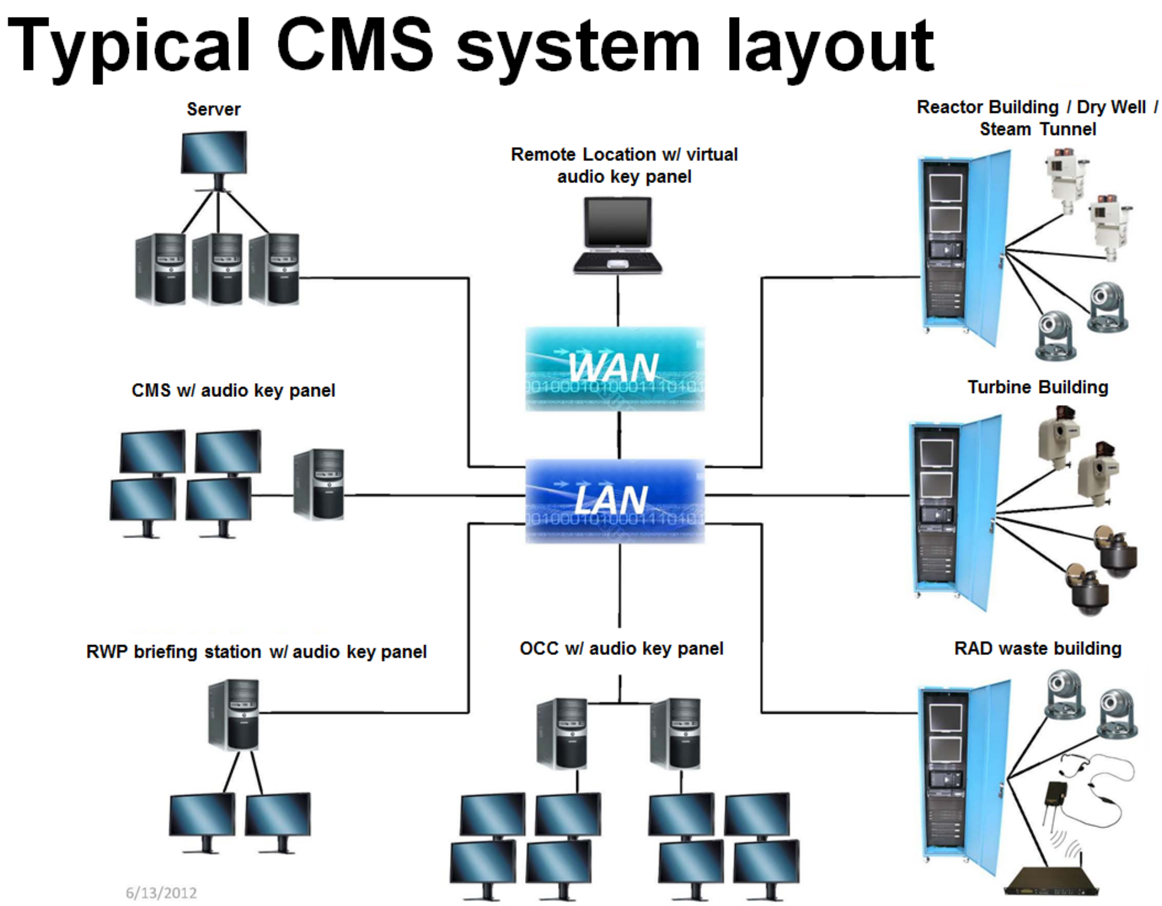

Fig. 6 – Typical Network Video Management System layout

Fig. 7 – Remote Monitoring Crash Cart

Remote Visual Inspection

Remote visual inspection systems have evolved from somewhat basic tools used to perform crude inspections and characterization to robust devices used to perform tasks that humans cannot. Most of these capabilities have been made possible by the miniaturization of the components that comprise a tool or robot. For example, the continued advancement and downsizing of cameras used in cell phones has provided technology used in miniature video probes that can access areas as small as 4mm while providing very high quality, color images that can be evaluated by subject matter experts in a remote location.

Fig. 8 – Brooks In-Bundle Camera System (BICS) – width 0.100” (2.54mm)

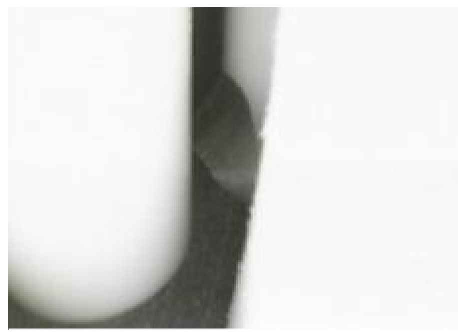

Fig. 9 – BICS image, machining remnant in a gap of 0.116” (2.95mm) gap

Remote Robotic Systems

Remotely operated robots add additional capabilities to the remote platform such as cleaning, testing and repair or dismantling. Robots in this category are as diverse as the applications they service, from small pipe crawlers used for characterization to robotic arms that deliver heavy payloads. The vast majority of these applications require a secure platform off which the end effectors or tools can be deployed.

Fig. 10 – Delivery platform - REPTIL

Fig. 11 – Service equipment - BICS

Fig. 12 – Delivery platform – SWATS Service equipment – Camera & retrieval tool

Remote robotic systems are divided into two main components: delivery platform and service equipment/end effectors. The delivery platform component delivers service equipment to an area to perform a specific task. Examples of delivery platforms include ground deployed remotely operated vehicles (ROV), submersible remotely operated vehicles (SROV) and unmanned aerial vehicle (UAV). The service equipment component is equipment that performs a service. In most cases service equipment is design as an interchangeable end effector that can be exchanged to allow the delivery platform to deliver a wide variety of services. Examples of service equipment include video cameras, ultrasonic testing (UT), eddy current testing (ECT) and radiation sensors, foreign object retrieval and sample recovery equipment, cutting, grinding and welding end effectors, and vacuum systems and laser ablation systems for decontamination.

Fig. 13 – ROV – Pipe walker FOSAR system

Fig. 14 – Submersible inspection system

Fig. 15 – UAV– Fukushima drone

Benefits

The benefits of remote technology typically fall into three primary categories, improving worker safety, access to confined or restricted spaces, and process improvements.

Worker Safety

Remote technology can be a valuable tool to improve worker safety. Reducing worker radiation exposure is of primary concern and remote monitoring systems allow the operator or inspector to have access to high quality visual feedback of the high radiation exposure area without being exposed to hazardous environments, such as poor air quality, high temperatures or radioactivity.

Confined Spaces

One area where remote technology has become invaluable is accessing spaces humans simply cannot access, most commonly because access is too restricted such as small diameter piping. In many cases such as piping, of the shelf technology is available that is both robust and cost effective. A very typical application is a crawler type device that looks similar to a small bulldozer that carries a pan, tilt and zoom camera with integrated lights. This is normally tethered to the control system and can act as a retrieval cable, should the device fail. More complicated applications with several restrictions may require special adaptations to navigate through complex geometries such as specialized containers or tanks. The primary benefit to using this type of device is it allows characterization of the restricted area without requiring potentially confined space entries or dismantling processes.

Process Improvements

Another high value benefit of remote technology is the potential for improvement in quality and productivity without sacrificing worker safety. Applications such as characterization of piping and tanks that are full of water for example can be examined without draining the tank, thereby reduce the overall time required to perform the task. Remotely operated robots can also deliver heavy tooling such as cutting or grinding machinery into tanks, vessels and piping that would be beyond the capabilities of a worker to safely manipulate.

Considerations

The most basic of considerations for remote technology applications are environmental, repeatability and precision, and cost.

Environmental

Remote monitoring and robotic technology can easily operate in temperatures from 0° to 50°C and $1x10^4$ RAD rates, beyond that specialty equipment will likely be required.

Working loads on the delivery platform will need to be closely examined. The total payload, precision of movement, repeatability and any additional forces in play such as counteracting support of a high pressure cleaning system or vibration of a cutting system are common considerations.

Cost

When considering a remote application, cost will be a key decision point. In evaluating the cost/benefit of the application, there are many factors such as the value of worker safety. Since it is extremely difficult to put a figure on worker safety, it does lead to a challenge to the traditional model of cost/benefit analysis in putting a figure on the cost of doing business with the current process and how much could be recovered with the new remote process.

Advances in monitoring technology allow the system to process automated routine monitoring tasks that keep personnel out of harm's way such as the use of sophisticated video analysis software to monitor restricted high dose areas for unauthorized activity. In this example, the system is certainly keeping the worker safer but how confidently can the operator put a cost on the incident and others like it that can be used in a cost/benefit analysis.

Whatever the case for a specific application, it should be anticipated that the reasoning for investing in remote technology for worker safety will require some probing questions. One question that can be used as a starting point is "what is the cost of not changing?" In addition, the following questions may be useful.

What is the direct, indirect and opportunity cost of:

- Dose
- Accidents
- Labor
- Errors (rework)
- Lost schedule time
- Lost operating time

If a legitimate case is to be made to decide to invest in remote technology based on a significant amount of research will need to be done by the operator to identify the true costs. Several assumptions are likely to need to be made which will require buy in from stakeholders. Because of this certain level of subjectivity in the analysis, it should be well understood and communicated as to what the definition of success will be.

APPLICATIONS

Remote Monitoring

Remote monitoring technology is routinely used to monitoring personnel, equipment and processes to ensure safety, quality and production goals are achieved. Video camera and audio systems are installed to view hazardous areas, such as high radiation and contamination areas, to support working parties. Radiation Protection (RP) personnel can use these systems to support pre-job briefings to provide a better understanding of the hazards associated with an area. RP personnel can use the existing remote monitoring system in conjunction with teledosimetry to help working parties micromanage their radiation exposure. These same systems can be used to increase personnel safety by reducing the number of personnel in the area during fire watch activities, security rounds and work supervision. Remote monitoring systems support the quality and production of work by allowing supervision and quality personnel the ability to view work streams in process, allow for independent oversight of activities and to ensure smooth transition between working parties when a work stream is complete.

Characterization

Remote robotic technology has been used to provide characterization of hazardous areas since the development of the visual inspection systems. Video camera end effectors are the most common systems for characterization. During the Chernobyl event, on site personnel used a toy tank and video camera to visually inspect a column of solidified fuel containing material (FCM). A fuel facility in Europe used a remote delivery platform and pan and tilt camera system to characterize the contents of radioactive waste silo. The system was designed to jettison the pan and tilt camera system post inspection to reduce the risk of personnel radiation and contamination exposure. Characterization of a hazardous space is a key element to developing a remediation plan.

REMEDIATION ACTIVITIES

Cleaning and Decontamination

Remote robotic technologies are used to remediate hazardous areas through cleaning. Remote robotic delivery platforms are designed to deploy a variety of end effectors to clean and decontaminate hazardous spaces. Cleaning and decontamination end effectors can be designed to use vacuum force, laser ablation, cleaning fluid dispensers, grit blasting, heat application, ultrasonic cleaning and mechanical agitating systems. End effectors can be designed to use compound systems in tandem to provide a wider spectrum of cleaning and decontamination services. For example laser ablation and cleaning fluid dispensing systems can be coupled with a vacuum system to recover debris and fluids created during the process.

Repair and Dismantling

Just as remote robotic techniques are capable of deploying into hazardous areas for cleaning and decontaminations, these systems are also capable of deploying end effectors to repair and dismantle components. End effectors have been designed to affect repairs, such as welding, grinding out defects in welds and the applying surface preparations. End effectors for dismantling and decommissioning have been designed to cut components with shears, abrasive wheels and torches.

Cost/Benefit Examples

Navigator – Financial and Process Improvement

In the late 1990s the US Department of the Navy was interested in reducing costs during the construction of the new class of aircraft carrier. They were seeking a solution that would reduce the foreign material close out of components associated with the primary coolant system. The challenge was to internally visually inspect 100% of a 20 inch (0.5m) mirrored finish pipework system. The system had to have the capability to navigate around multiple system protrusions and openings, and through a 20% pipe ID restriction. The system had to be capable of removing adhered, dried debris and adhesive reside, retrieve objects up to one pound in weight, ability to measure weld concavity and convexity. The entire remote robotic system had to meet detrimental material and encapsulation requirements and be fail safe, such that it could be retrieved safely from the pipework without damaging the interior surface during a power outage.

The final project was a remote robotic system called Navigator. The system used an eight legged delivery platform capable of rotation within the pipework to allow the system to navigate around system protrusion and opening. Each leg was outfitted with a video camera with integrated lighting package to monitor movement. The system utilized several service systems to deliver inspection and retrieval services. Mounted on the forward end of the delivery platform was a high resolution pan, tilt and zoom color video camera system with integrated lighting package, capable of detecting particulate debris as small as 0.005 inches (0.13mm). The pan and tilt camera included an integrated laser line generator to allow for measurement and analysis of surface feature including welds. Laser line accuracy was +/- 0.015 of an inch (0.38mm). Two retrieval end effectors were mounted radially on the delivery platform. The first was a mechanical gripper capable of retrieving objects up to one pound in weight. The second and third end effectors were designed as cleaning systems. One end effector was capable of deploying and recovering cleaning fluids, wiper for interrogating stains and removing tape residue and vacuum to remove particulate and construction debris. The third end effector was designed as a spatula to remove tape residue. Both end effectors incorporated video cameras with integrated lighting packages to monitor services.

Overall, Navigator was successfully deployed; saving the customer $50,000,000 and reducing foreign material close out by several months.

Remote Monitoring – Personnel Radiation Reduction and Process Improvement

Commercial nuclear power plants shut down once every eighteen months for a refueling and maintenance outage. During this time the plants personnel population will double or triple during the outage. With the addition of personnel unfamiliar with the plant design and constantly changing conditions with plant configuration, managing personnel radiation exposure and safety becomes a challenge.

Radiation Protection departments deploy network video management systems and audio systems to monitor working parties in hazardous areas and communicate with this parties to assist with the management of their radiation exposure. The process for protecting radiation workers typically begins six months before the outage. RP personnel will identify contamination and radiation areas for monitoring. Each area will be evaluated based on its risk to personnel, size and nature of work in order to ensure the appropriate audio and video equipment is selected. Some to the equipment characteristics that are identified per areas are whether wireless or wired audio systems can be used, where to installed wireless receivers, the use of fixed mounted or pan and tilt cameras are appropriate, location of audio/video nodes within containment, transmission path from containment, and location of the control stations outside containment.

Mobile network video management solutions, also known as Crash Carts, have been designed to reduce setup and pack up times. These Crash Carts are capable of video, audio and telemetry communication, integrate a variety of camera systems, such as IP cameras, fixed cameras and pan and tilt compatible camera systems and act as a node for the transmission of network protocol.

Remote monitoring is an integral element to the management of personnel radiation exposure. It has been estimated that plants save approximately 20 REM per outage, through improved pre-job briefings, reduction in RP personnel at the point of work and improved monitoring of working parties at the point of work.

The added benefit of installing remote monitoring systems is improvement in work process monitoring and working party hand offs. Outage Control Centers (OCC) have access to remote monitoring systems and are capable of monitoring the progress of critical work. OCC personnel are capable of redirecting work in case work streams fall short or gain schedule time. Additional during cutting, grinding and welding, fire watch personnel are required to monitor the work post service. Without remote monitoring system, fire watch personnel must stay at the point of work before, during and after the work. Remote monitoring systems allow fire watch personnel the ability to monitor this area remotely, thereby reducing personnel radiation exposure and environmental risk.

REPTIL – Personnel Radiation Reduction

In commercial nuclear power plants the heat exchanger between the nuclear reactor and the turbine is called the steam generator. Radioactively contaminated coolant passes through the inside of the steam generator tubes, while secondary water passes over the outside of the steam generator tubes. The secondary water is converted into steam, which is piped to the turbines to be converted into electricity. The steam generator tube wall thickness is 0.020

inches (0.508mm); this is the thinnest boundary between the nuclear reactor and environment. It is vitally important that this boundary remain intact for public safety.

During reactor outages, plant systems are opened for maintenance and inspection. Plant procedures mandate a program to exclude the introduction of foreign objects from systems. Secondary side systems are particularly venerable to foreign object intrusion due to the size of opens and the large number of personnel working on the system. Any foreign object introduced into the secondary side system, from turbine to feedwater pumps, will be flushed into the steam generator.

Foreign Object Search and Retrieval (FOSAR) services are routinely performed in steam generators to locate and remove foreign objects. The REPTIL remote robotic in-bundle inspection system was designed to deploy a video probe into the steam generator tube bundle. The video probe is a high resolution color camera with integrated light package, the total thickness of the probe is 0.100 inch (2.54mm). This allows the system to inspect in-between the tubes of all models of steam generator.

REPTIL reduces personnel radiation exposure by 80%, compared to manual in-bundle inspections. The system provides for repeatable inspection data and a superior image. REPTIL also reduces outage schedule time due to its ability to quickly and accurately perform inspections.