The Future of Robotics/Remote Handling Solutions for the Nuclear Industry-17347

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Introduction

The nuclear industry is seeing a resurgence of development and utilization of advanced integrated systems; fused sensor arrays; autonomous, remote and hybrid operations; and augmented reality display and control system interfaces. A new age of "robotics" and remote handling technologies. For many years the use of robotics in nuclear applications has been done sparingly due to technical limitations, perceived and real reliability issues, perceived and real risk concerns, and cost. Although robotics have been used successfully on a variety of projects globally, the underuse of this technology, particularly within the nuclear industry both public and private, is overwhelming.

As the number of complex, high hazard projects in the nuclear industry increases, the use of robotics for maintenance, inspection, repair, decommissioning, and remediation activities will become increasingly vital in the future. The risks associated with direct human exposure are high and thus eliminating the risk, or managing it to acceptable levels by using robotics/remote handling as well as other technologies is critical to success as more extreme environment operations and tasks are undertaken. Recent and ongoing advances in technology now allows us to safely and effectively remove the direct / in-situ human element from these type of activities. All the while delivering the same or better outcomes when considering the alternatives when limited or no direct / in-situ human intervention would be allowed.

The biggest obstacles the nuclear industry faces center on the cost, reliability, maintainability, effectiveness and appropriate uses of robotics/remote handling solutions in a nuclear (radiation and/or contamination) environment. In order to mitigate these concerns, a sound approach to the use of robotics needs to be addressed. This approach must include:

1. A better understanding of what technology is available and how it can be utilized across multiple sectors, e.g. Commercial Off-the-Shelf (COTS) technology modified / adapted for the nuclear sector;
2. How to implement technology in an integrated pragmatic approach that is cost effective by combining technological know-how / subject matter expertise (SME) with the equivalent subject matter expertise in regulatory, operational and maintenance requirements and limitations, such that a more complete set

of functional and operational requirements can be jointly developed in the process.

3. The integration of requirements (project, site, regulatory, etc.), risk management (human factors) and technology, i.e. a marriage between political, programmatic, and technological factors.

As the development of robotic/remote handling technology progresses and the successful implementation on projects is demonstrated, the better off the industry will be. This paper provides an overview of the fundamental issues facing the nuclear industry with regard to effective and successful technology selection, maturation, deployment, and integrated risk management, and offers suggestions on how we may overcome these persistent issues now and in the future.

Robotic use in the Global Market

In today's world, almost everyone has seen or been subject to "robotics" or alternatively, "automated" systems in their everyday lives. These types of systems are prevalent in such industries as automotive, manufacturing, food processing, health care, agriculture, and entertainment, just to name a few. The increased demand for automation in all aspects of our lives has contributed to the growing use of robots. Rising labor costs and shareholder demands for increased productivity and thus profit, have pushed organizations to automate their processes as market demand for products and services continues to increase. Technological advancements and growing adoption in diverse industries is at the forefront of the growing industrial scale robotics market trend. Most visible, and in no small measure a key contributor to the current resurgence in the use of robotics, is the stellar and continuing success and growth of the 'drone' products, markets, and industries.

So if the use of robotics and their capabilities are providing such a dramatic positive impact in other industries, why are they not so easily adopted into the nuclear industry?

Nuclear Robotic Needs

The need for nuclearized robotics is a necessity for a variety of nuclear activities where the reduction and/or elimination of human exposure to radiation, contamination and/or chemical or other hazard is mandatory. This is especially true where operations need be conducted in environments that may be lethal, impractical or otherwise inaccessible to direct human intervention. Specifically, the global nuclear market requires the need for inspections; integrity management; decontamination, decommissioning, de-activation, and dismantlement (D4); repairs; hazardous material (waste) handling, packaging, etc. The question is always asked, "why not just use commonly used robotics from other industries?" The answer to this question is predicated upon a number of factors including environmental conditions, regulatory requirements, site conditions, human factors, risk management, and technology integration.

First, legacy nuclear facilities, e.g. WWII / Cold War Era Weapons Complex sites, and aged or severely damaged commercial nuclear power plants, are so unique in terms of footprint, radiation and/or contamination levels, and difficult / unstructured operating environments, that traditional robotics often times cannot be used effectively. The reason for this is that these scenarios and theaters of operation have unstructured environments that do not lend themselves to traditional repetitive tasks. Every site or project can be and often is unique, therefore it is difficult meet all functional and operational requirements with a common system without tailoring it to the specific projects need. In other words, what might be successful on one project may have limited applicability or success at another project location (even at the same facility), based on site specific or regulatory conditions.

Second, the environmental conditions dictate a technologies usefulness. For example, the sophistication and capabilities that makes robotics useful in so many industries, are the same reasons why they may become a detriment for nuclear applications. Specifically, many of the systems utilized in and/or developed for other industries are developed with sophisticated control systems which require, in many cases, a complex series of electronics, cables, sensors, etc. Since rad hardening (radiation exposure survivability), contamination control, and / or secondary exposure to operations and maintenance personnel needs to be considered for every component in a nuclear robotic application, many of these systems simply cannot be used because of limitations imposed by the nature of their design and sub-component environmental limitations, e.g. electronics burnout and/or they become too contaminated to operate and maintain. This becomes very costly considering the amount of investment made in these types of systems. This condition is greatly misunderstood and is a requirement that few suppliers can adapt to. For this reason, many commercial off-the-shelf robotic providers have a hard time customizing their systems for "one off" nuclear applications. Further, first of a kind (FOAK) / one-off designs are contrary to their production and/or profit models.

A Focus on Nuclear Robotic Development

Since the mid 1980's, robotics deployed in the nuclear sector have been used in a variety of different ways. From commercial reactor maintenance/inspection to facility D&D and emergency response and disaster response, recovery, and stabilization (think Three-Mile Island, Chernobyl, and Fukushima Daiichi), robotics have played a major role globally. Today, robotic development for the nuclear industry continues to progress with many new technologies being established such as those being explored and developed under the US DOE elements of the National Robotics Initiative, Sellafield Limited Innovation Framework [1, 2], and parallel programs seen in the European Union and Asia by the IAEA as well as the supporting private and public enterprises.

Currently, substantial markets for robotics use in the nuclear industry are in the environmental restoration and D4 efforts being undertaken by the US (Department of Energy), the UK (Nuclear Decommissioning Authority) and Japan (Fukushima). Robotics have been used successfully in these markets on some of the world's most challenging projects where the minimization of human exposure, as well as the mapping and characterization, let alone necessary operations in these hostile and hazardous environments is critical to a successful outcome. Figure 1 provides recent examples of decommissioning projects that have used robotics/remote handling systems successful. This list includes, but is certainly not limited to:

- Three-Mile Island (TMI) Stabilization
- Chernobyl Stabilization
- Brookhaven National Laboratory - Graphite Reactor Decommissioning [3]
- Fukushima – Spent Fuel Pool, Fuel Rod Assembly Retrieval [4]
- Fukushima – Reactor Inspection and Repair [5]
- Sellafield – Dissolver Vessel Segmentation [6]

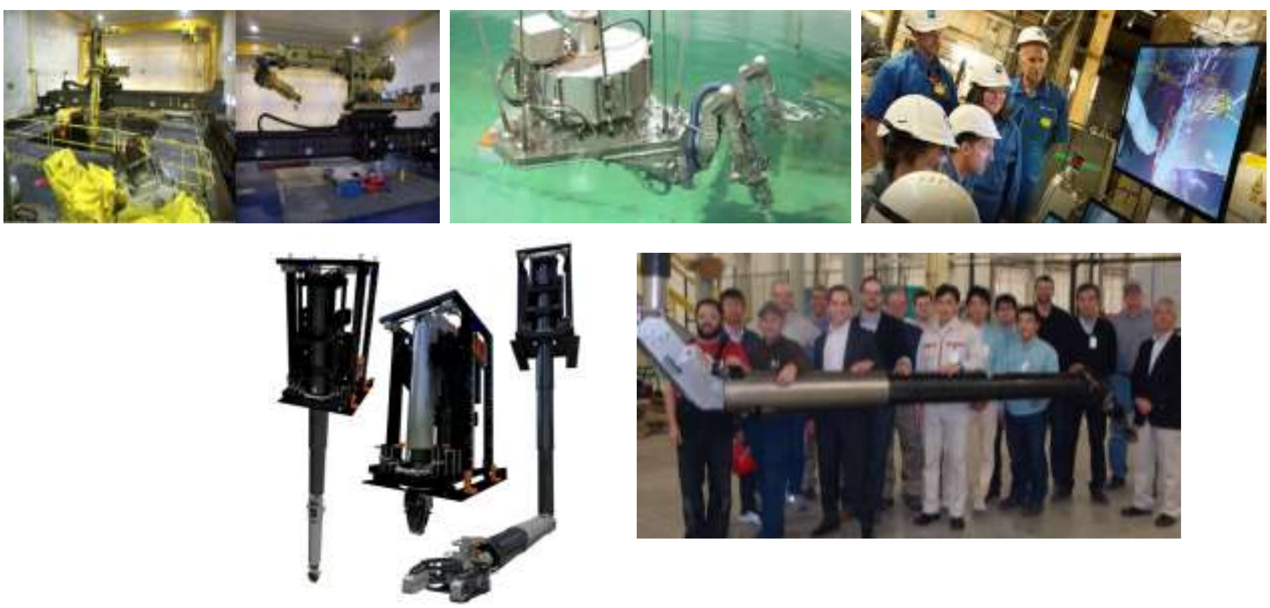

Figure 1 - Left to right - Brookhaven Reactor D&D, Fukushima Fuel Rod Retrieval, Sellafield Dissolver Cutting, Fukushima Reactor Inspection and Repair

Obstacles Facing Robotic Development and Use

From the examples above, these types of success stories are sporadic and few and far between. Often these projects are contingent upon site specific prioritization, government spending, and risk tolerance. This is specifically true for decommissioning activities. It has never been a matter of "if" these projects will be done, its "when" will they be done. Most decommissioning projects deal with extreme environment/unstructured environments that people simply cannot operate in. Historically decommissioning projects take the simpler approach and overlook the use of robotic capabilities. Many look at robotics as complex with no one qualified in house to manage the risks or complexity. While there is merit in the KISS (Keep it Super Simple) principle, the appropriate use of robotic/remote handling technology may well accelerate schedule and save project and site closure costs in the long run.

One of the other obstacles facing robotic suppliers and end users is delivering "the right tool for the right project". Because of the rising need for robotics, many suppliers have entered the market claiming that they have the engineering background and expertise to meet the rising need for robotics. Herein lies one of the biggest issues with robotics in the nuclear industry. Too often systems are being developed that either 1) never get deployed because of technical limitations, 2) are not reliable or maintainable or 3) are cost prohibitive. All three of these issues are largely driven by failure to consider early on in the process the integrated set of functional and operational requirements and environment considerations of the tasks at hand AND of the technology solution being offered and/or developed. As a result, the term "robotics" has often turned into a negative term in many nuclear circles. Comments such as, "robots don't work", or "they are too expensive and unreliable" get said by many end users that have had disappointing results. This perception will continue to grow if the right approach to the fundamentals associated with the development of these types of systems is not used going forward. The blame for this is shared by both the suppliers themselves and the end users who often times do not understand the correct way of integrating technology with site and operational requirements.

Too often robotics for the nuclear industry are developed without a clear objective in mind, or worse yet there is a clear objective – but a poorly defined set of requirements and operating environment challenges, as well as a poorly defined set of expectations and definitions of "success". Expensive RDDT&E (Research, Development, Demonstration, Testing, and Evaluation) activities, and/or COTs system modification and adaptation efforts are undertaken to develop robotics without fully understanding the appropriate operational use of these systems. The reliability and risk of failure in this instance becomes a very important subject that will directly affect the outcomes for the project, as well as the use of these systems throughout the industry now, and in the future. For example, individual robotic systems that fit a common objective may be available, however they typically need to be modified and tailored to meet a specific set of requirements. A successful example of this principle was the use of a modified "remote" excavator unit that was deployed on the reactor decommissioning project at Brookhaven Nation Lab [3] shown in Figure 2. Here, off the shelf components were modified to meet the technical and operating environment challenges, as well as the site programmatic and risk management requirements for decommissioning. Knowing when to use the right tool and how it can meet the integrated set of requirements for these types of projects is critical to a project's success. This ties back to the complexity of the systems (including cost) and their viability in a highly radioactive environment. Particularly in nuclear decommissioning, there will always be a balance between capability and the cost of robotic systems.

Figure 2- Brookhaven modified remote excavator

Integration of Robotic/Remote Handling Technology

As mentioned previously, there are several initiatives underway promoting the use of robotics and their development for the nuclear industry. In theory, this is an excellent example of being proactive by recognizing an underserved market. However, the concern is that what is being developed is being done without an end goal in mind. Based on R&D and complex designs, the fear is that these systems will be costly to develop with reliability concerns and risk of failure and recovery. Nuclearized robotics should not normally be looked upon as a "one size fits all" approach. Every aging facility has various constraints due to the ambiguous environments they are in and operational requirements specific to the site itself. Constraints such as the facilities layout, radiation/contamination levels, and operational limitations imposed by the site all contribute to the appropriate solution selection, adaptation, and use of robotics systems. Even though we would like to think so, the use of a common developed system that can be used regularly on a variety of projects is unrealistic, albeit a challenge being worked upon by a number of universities, commercial system providers, and systems integrators. Now, and for the immediate future, best practice suggests that bridging the gap between commercial off-the-shelf items or proven designs and “state of the art” technology whose functions and requirements have been mutually agreed upon early in the project by an integrated team of SMEs, should be used to manage the integrated risks on these complex projects. An example of this is shown in Figure 3 where a tank cleaning manipulator used at Trawsfynydd (UK) became the basis of design for the Inspection and Repair manipulators deployed at Fukushima. Although on the surface these systems look identical, each are in fact customized to meet the operational and regulatory requirements of the individual site conditions. This is an example of taking a proven design that was customized to meet a very specific set of requirements at Fukushima.

Figure 3 - Trawsfynydd Tank Cleaning Manipulator and Fukushima Inspection/Repair Manipulator

It is critical as a supplier and end user, that we understand robots by themselves are only a piece of the solution. Equally important is taking the time to develop an integrated project team from the early planning phases of the project, a clear philosophy for the integration and deployment of these systems, and for what purpose and to what end these systems will be utilized, how these robotic systems fit into the larger scheme of the project, as well as a clear and vetted set of requirements and definition of the operating environment. Therefore, understanding the differences between products versus integrated solutions for complex nuclear related tasks is critical. Nuclearized robotic systems, namely off-the-shelf products, are typically beneficial for small, relatively straightforward activities such as inspections, sampling, monitoring, etc. These products by themselves are an integral part to successful remote activities in nuclear environments. However, they by themselves do not provide a complete solution when it comes to large-scale decommissioning activities, for example. Instead, if used appropriately, they become a part of the overall solution when integrated with the rest of the project needs.

Often times the misuse of these types of products are what slow down the acceptance within the industry and in some cases provide misleading information. Too often, the users of these systems try to force them, i.e. make them "fit" a particular task(s), that they were not designed or intended for. For example, radioactive tank cleaning projects often require multiple technologies for tank closure activities. The reason? The unique nature of each set of tasks and each set of operational limitations that need to be overcome as the project unfolds. Many systems that were advertised to accomplish multiple tasks never live up to expectations. The reason for this is that the users of these technologies do not understand their actual capabilities and/or limitations as constrained by each operating environment and set of tasks. As a result, robotic systems are criticized and/or deemed a failure more often than they should be. If the right technology is properly identified, used correctly and expectations are communicated properly, this misperception can be avoided.

CONCLUSIONS

Robotic systems and solution experts that are focused on the integration of proven technologies – and that are an integrated part of the project team from its onset - are a necessity for successful planning during nuclear operations. The approach to nuclear operations should always be, "what is the simplest, most effective way we can approach a particular project need?". Understanding and implementing the right technologies is where the true value will be recognized. The integration of systems, which includes more than just robotics, is key when developing schemes for these types of complex operations. Often times during planning, the remote handling needs of the job are set aside to be evaluated at a later time due to risk concerns and lack of knowledge. The issue is, experts in the area of robotics or remote handling are rarely involved in the upfront planning. As a result, unnecessary constraints, risks, and obstacles are imposed on project teams to deliver. If done intelligently, this should be introduced at the forefront of planning. Using this type of sound approach leads to effective task organization for the end user.

By developing an overall philosophy that leverages proven technologies with implementation expertise; i.e. solutions versus products, is a recipe for success. This is the area that is underappreciated in the industry and one that needs to be recognized on a much broader scale.

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