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Articulated Robot Arms For Inspection Task In Nuclear Power Plants –Trends, Methods And Motivation For New Design Approach

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Abstract: The Robots represent an integral part of manufacturing and materials handling equipment and can be used in a wide variety of applications. Industrial robots are programmable, multi-function manipulators designed to automate tasks such as welding or the movement of materials through variable programmed motions. Now a day the articulated robot arms are effectively utilized in the area of inspection process like welding defects, pipeline inspection and nuclear pressure vessel online inspection using advanced controls technology. Many of the researchers and industrialists illustrated the complete knowledge about the design, and analysis of these types of articulated robots for inspection purposes. This paper focuses the important research works on design and analysis of a generic articulated robot arm to carry out the inspection process in nuclear reactor. This paper consists of an identification of the leading technical issues concerning the application of articulated robot arm in the inspection field also suggest the new mechanical design of robot base actuation.

Keywords – Articulated robot, Robot inspection, Telescopic type arms

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I. INTRODUCTION

Robotics focuses on systems incorporating sensors and actuators that operate autonomously or semi-autonomously in cooperation with humans. Robotics research emphasizes intelligence and adaptability to cope with unstructured environments. In many industrial applications of robots, the objective is to replace human workers with machines that are more productive, efficient, and accurate. One dominant aspect of improvement in nuclear power plant operation is now the very high speed in the development and introduction of computer technologies that are bringing continuous changes into the design of plant instrumentation, control, and safety systems. Associated with the recent advances in electronic controls have been significant developments in the field of robotics.

II. MOTIVATION OF THE WORK

The aim of the literature review is to search, analyze, and document the previous researches related to robot inspection in nuclear reactor. This review helps identifying the 'knowledge gap', i.e. the knowledge that is missing from the previous work. The information collected in this paper will give a support to achieve the further developments of the robot design tasks.

II.a. Trends in Remote Handling Device Development in Nuclear Environment:

Raimondi et al., a brief review is given of studies on layouts and methods for handling some major components requiring remote maintenance in future fusion reactors: neutral sources and beam lines, the blanket, diverter plates, armor tiles and vacuum pumps. Comparison is made to problems encountered in JET, methods and equipment used and development work done. Areas requiring development and research are outlined. These include topics which are the subject of papers presented here, such as dynamic studies and control of transporters, improvements to the man-machine interface and hot cell equipment. A variety of other topics where effort is needed are also mentioned: environmental tolerance of components and equipment, TV viewing and compensation of viewing difficulties with aids such as computer graphics and image processing, safety assessment, computer aids for remote manipulation, remote cutting and welding techniques, routine in-vessel inspection methods and selection of connectors and flanges for remote handling. They concluded that it is evident that a vast programme of research and development will be needed if an acceptable level of reliability is to be achieved in remote maintenance of a fusion reactor. Maximum emphasis should be given to key issues that have direct impact on the layout of the machine. The feasibility and reliability of cutting, aligning and welding joints and pipes has to be established early on. Designers need to get a clear idea of operations to be done within the vessel and the functions required of the end effectors before finalizing the design of the transporters.

II.b. Design and Development of Robot for Radiation Protection Assistance:

Jahan zeb et al., designed a mobile Radiation Protection Assistant Robot (RPAR) to assist radiation workers in a hostile radiation environment. The RPAR comprises of a cubicle tri-wheeled platform and a four Degree of Freedom (4-DOF) serial type articulated robotic arm. The movement of the platform is controlled by two differential wheeled driving systems. The RPAR is helpful in radiation mapping, handling and transportation of radioactive material. It can also be helpful in radiation emergencies. The kinematics study and manipulator Jacobian of the gripper of articulated robotic arm has been assessed and workspace analysis is made. Radiation hardening study of the electronic components of RPAR driver modules has also been carried out to ensure the safe operation up to a total ionizing dose of 9 Sv. They concluded In a nuclear installation the congested work space and restricted time period is problematic to work freely. RPAR has been designed and developed to assist radiation workers in those areas of nuclear installation that are beyond the safe approach for human. To achieve better performance of a robotic device, kinematics and the manipulator Jacobian analysis are the most important considerations for maximum utilization of an articulated robotic arm system either with fixed or mutable platform.

Senthilkumaran et al., implemented the Automation of non-destructive evaluation (NDE) methods and use of robotic devices for inspection result in significant performance enhancement in terms of efficiency cost and time. This has resulted in the development of many custom-built robotic devices, especially for applications of NDE for quality control, material characterization, in-service inspection and material assessment. The state of art of inspection of vertical surfaces by deployment of robotic devices is highly sophisticated. The robots are to be tailor made for the specific task. They highlighted the various parameters and optimization of suction cups used for maneuvering robots on vertical surfaces. The robotic devices consist of, a) power source, b) an operative /manipulator mechanism c) locomotion of the system, d) control system, e) a sensor or feedback system, and f) the end effectors. The operative /manipulator system is the mechanical, electrical and pneumatic hardware for the robot. The end effectors are manipulated to achieve the desired operation by the aided of the locomotion, control system and feedback system. The end effectors shall house the Sensor, integrated sensor amplifier, which is connected to inspection module. The inspection module consists of a) signal generator and receiver, b) controller, c) display, d) data processor and e) data storage and retrieval system.

II.c. Design and Modeling of a Long Reach Articulated Inspection Arm (AIA):

Laurent Gargiulo et al., developed an Articulated Inspection Arm (AIA) is currently developed by the CEA within the European work programed framework, which aims at demonstrating the feasibility of a multi-purpose in-vessel Remote Handling inspection system using a long reach, limited payload carrier (up to 10 kg). It is composed of 5 segments with 8 degrees of freedom and a total range of 8 m. They validated concepts for operations under ITER relevant vacuum and temperature conditions. After qualification, the arm will constitute a promising tool for various applications. Several processes are already considered for ITER maintenance and demonstrated on the AIA robot carrier were the first embedded process is the viewing system. It was already manufactured and allowed close visual inspection of the complex Plasma Facing Components (PFC) (limiters, neutralizers, RF antenna, diagnostic windows, etc.).In situ localization of water leakage based on a helium sniffing system is also being studied to improve and facilitate maintenance operations.

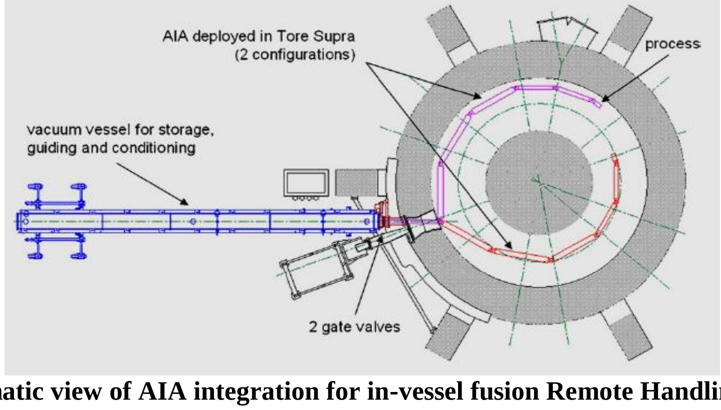

Fig 1: Schematic view of AIA integration for in-vessel fusion Remote Handling inspection.

II.d. Implementation the Wall Climbing Robot Concepts:

B.L. Luka et al. they suggested to use the wall climbing robots for nuclear inspection purpose also stated that the Nuclear reactor pressure vessels are often required regular inspection and maintenance in order to ensure the safety of the reactors. Failing to carry out proper maintenance could cause severe casualty. The usual way of carrying out inspection in these hazardous environments is using long reach fixed base manipulators. However, these manipulators suffer from low payload capacity and relatively large end point deflections. Also, the installation and the storage of these long manipulators could be costly. An alternative solution is to use walking-climbing robots, which overcome the problems encountered by the long reach manipulators. In their work, two robots, NERO (Nuclear Electric Robot Operator) and SADIE (Sizewell A Duct Inspection Equipment) which have been applied successfully to inspect two Magnox reactor The aim of the literature review is to search, analyze, and document the previous researches related to robot inspection in nuclear reactor. This review helps identifying the 'knowledge gap', i.e. the knowledge that is missing from the previous work. The information collected in this paper will give a support to achieve the further developments of the robot design tasks.

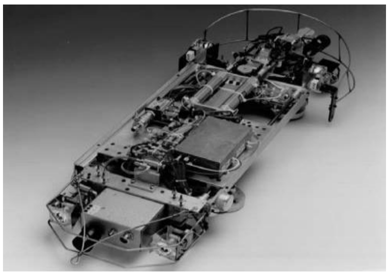

Fig 2: NERO (Nuclear Electric Robot Operator)-wall climbing concept.

III. OBJECTIVES

Now, however, developments are taking place rapidly as electric utilities have begun to consider the potential uses of robotics in nuclear power plants. One of the most obvious reasons for the shift in attention is the robot's ability to work in hazardous environments such as the high temperature, high humidity, and high radiation areas found in nuclear power plants. In these areas working conditions are difficult, not conducive to high quality work, and human access is restricted, or severely hampered by protective clothing. In some cases robots offer the potential to do work that simply cannot be matched by humans. In other cases, robots offer the possibility to improve availability by shifting some outage activities off the critical path. For example, some surveillance and maintenance tasks in the reactor containment, which are normally performed only when the reactor is shut down, may be performed by robots while the plant is on-line. In nuclear applications where quality assurance measures are essential and often.

IV. THE NEW APPROACH OF MECHANICAL DESIGN OF ARTICULATED ARMS IN INSPECTION PURPOSE

Many of the research gaps could be identified from the literature reviews, whenever the articulated arms are used in the nuclear reactor inspection the following are the major considerations space available for installing the new robot, stability, repeatability, accuracy and self-weight etc.

In the past researchers mainly not focuses the implementation of the telescopic type, the rack & pinion and screw jack (base mechanism) type articulated arms for inspection. these types of arms are occupy less floor space and more stability then comparing to the other arms this also gives the long reach conditions. So in our research we emphasis the implementation of these types of arms for nuclear reactor inspection.

IV.a. Preliminary concepts on Telescopic R-θ Arms:

The proposed concept was an R- θ telescopic manipulator arm. This design is commonly referred to as a cylindrical type robot arm and uses telescopic and rotational motion to manipulate throughout the workspace. This design is similar to common telescopic boom lifts, with the imposed limitation of planar motion, parallel to the workspace. The telescopic structure is accomplished through a series of prismatic sections that are rotated from the largest, base section. Rotational and telescopic actuators control the arm movement and provide complete end-effector position measurements. The advantages of this design include the simplicity of the two-axis kinematics, compact storage size, and the vast workspace coverage. The main disadvantage is the lack of commercially available components, such as sections, actuators, etc. Although there are numerous material handling machines, these machines are designed for carrying much larger loads and do not incorporate accurate positioning systems.

IV.b. Telescopic Actuation Concept Selection:

Determining the actuation system for the telescopic sections began with brainstorming and research into current methods used in telescoping boom cranes, material handlers, and personnel lifts. Through this research, several actuation concepts are going to be formulate including cable-pulley configurations, parallel screw configurations, and telescoping hydraulic cylinders.

IV.c. Cable-Pulley Configurations:

Cable-pulley configurations provide for a simple cost-effective means of actuating nested telescopic sections. One end of a continuous drive cable is connected to the inner end of the section to be actuated. The cable is then routed outward along the inside of the outer section around a pulley located at the outer end of the outer section. The cable is then routed along the outside of the outer section and wrapped around a cable drum several times. Next, the cable is routed around a pulley and into the base end of the outer section. Finally, the cable is connected to the base end of the inner section. A motor initiates extension and retraction by rotating the cable drum clockwise and counterclockwise, respectively. Additional telescopic sections can be actuated using the single cable drum and a more complex cable routing.

IV.d. Parallel Screw Configurations:

Parallel screw configurations are another common method used in telescopic applications. This design incorporates a series of ball/lead screws aligned parallel within the telescopic sections. The screws are connected such that rotation of the first screw causes rotation of the remaining screws at the same rate. To actuate the sections, each screws nut is connected to the corresponding section, i.e. the first screw's nut to the first telescopic section. In addition the subsequent screws are connected to the previous sections such that they extend along with the sections.

IV.e. Telescopic Hydraulic Cylinders:

Telescopic hydraulic cylinders, as shown in Fig 2.are another method commonly used in telescopic crane booms, and other industrial applications. Telescopic cylinders are composed of a series of prismatic hollow tubes concluding with a smallest solid rod. As fluid enters the cylinder, the solid rod is pushed outward, subsequently pulling the nested hollow tubes along with it. Advantages of this design include commercial availability, robustness and simplicity of design. However, there are associated disadvantages of telescopic hydraulic cylinders. The first is the lack of constant velocity motion due to volumetric changes within the cylinder through extension and retraction. In addition, in order to obtain accurate positioning from the cylinder, an external measurement device and complex hydraulic control would be required.

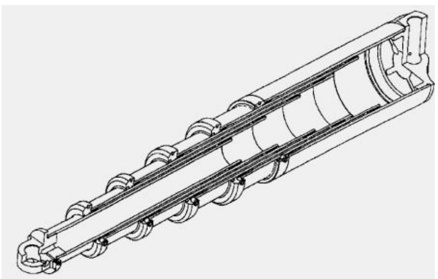

Fig 3: Telescopic Hydraulic Cylinders for Robot actuation

IV.f. Advantages of rack and pinion & screw jack type base mechanism articulated arms:

A rack and pinion gear mechanism is a very efficient way of directly transferring rotary motion into linear motion. By varying the sizes of either the rack or the pinion, the rotation / linear travel ratio can be varied according to the requirement criteria. Furthermore, force variation can be designed in by varying the size of the pinion.

A rack and pinion is a type of linear actuator that comprises a pair of gears which convert rotational motion into linear motion. The circular pinion engages teeth on a linear "gear" bar–the rack. Rotational motion applied to the pinion will cause the rack to move to the side, up to the limit of its travel. the best known mechanism yet to convert a rotary motion into a linier one, the rack and pinion can only work with certain levels of friction. Too high a friction and the mechanism will be subject to wear more than usual and will require more force to operate. The most adverse disadvantage of rack and pinion would also be due to the inherent friction, the same force that actually makes things work in the mechanism. Due to the friction, it is under a constant wear, possibly needing replacement after a certain time. The mechanism is no longer the way it was in the old days though, to prevent backlash and to minimize any possible friction, the later versions were introduced with

teeth to match in both products. Plenty of other changes have been made to enhance the mechanical advantage of the mechanism.
A mechanism for lifting and supporting loads, usually of large size. A screw jack mechanism consists of a thrust collar and a nut which rides on a bolt; the threads between the nut and bolt normally have a square shape. A standard form of screw jack has a heavy metal base with a central threaded hole into which fits a bolt capable of rotation under a collar thrusting against the load.
These types of mechanism in robot design must provide the higher work volume and rigid mechanical structure also provides the high mechanical advantages.

V. CONCLUSION

This paper motivates for the future research works on modeling, simulation and analysis of a generic articulated robot arm for inspection in nuclear reactor which is basically focuses on the concept of design and implementation of the telescopic, rack & pinion and screw actuated type articulated arms .The further work includes the mathematical and software oriented design, kinematics, dynamic, and workspace analysis of the articulated robot arm with all the feasible solutions.

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