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Robotic System for Pipe Wall Thickness Inspection for the Angra1 LTO – Conceptual Project

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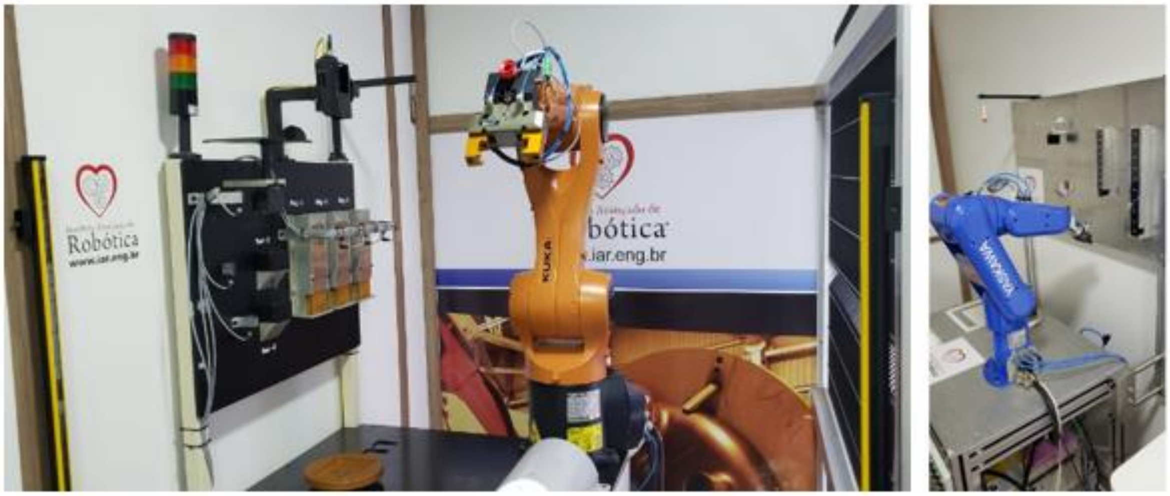
1. Introduction

In 2025, the Angra 1 nuclear power plant completes 40 years of operation and Eletronuclear decided not to decommission it, but instead to request the Brazilian nuclear regulatory body to extend its operational life and renew the operating license for another 10 or 20 years. For Long Term Operation (LTO), it is necessary to carry out a wide range of plant aging management programs and carry out, when necessary, the adaptation of its structures, systems and components (SSCs) [1,2]. The plant must undergo numerous inspections and a general assessment, and possibly recover or replace systems aged by 40 years of service that do not meet the regulatory agency's criteria to remain in service [3,4]. Several inspection activities must take place in their SSCs located in hostile areas, contaminated with radioactive material or not and high temperature and high humidity. In these areas, the use of robots is expected to reduce the rate of workers' exposure to these hostile conditions, reduce execution times and to improve data collection and analysis [1-4].

This work aims to present the progress of the project of inspection of pipes of the secondary system from Angra 1 power plant using robotic systems integrated with Industry 4.0 technology. It is about automating component inspections (nuclear plant piping) according to the XI.M17 aging management program [1]. Erosion and accelerated corrosion processes induced by fluid flow are important aging processes [5,6] and are monitored through inspections that seek to determine the reduction in pipe wall thickness.

The use of robots and artificial intelligence permeates all technological areas, including nuclear energy, which has complex processes common to all technologies and, additionally, with hostile environments. The expected difficulties are related to hot and humid environments (50 degrees Celsius and 100% relative humidity), spaces with complicated geometry such as pipeline curves and their support structures [7]. The need to use intelligence to handle collected data is also important. Processes called Industry 4.0 (I4.0) are applicable to the XI.M17 aging management program because they allow them to be distributed throughout the technical-managerial structure of an organization [1,2,8-10]. One of the concepts that will be widely used in I4.0 is the Digital Twin, which, from a production perspective, incorporates the virtual context into the real context of a production system. Digital Twins are very realistic virtual models, which allow interaction with the real world environment [10]. They include equipment, and all the steps to carry out a certain production process. Virtual Commissioning can be used during the development of automated processes and helps to systematize the configuration procedures necessary to implemented them with better quality.

2. Robotic systems, instruments and methods



1a 1b

Figure 1 – Robotic systems. 1a) KUKA Cell; 1b) YASKAWA MOTOMAN Cell.

The KUKA Cell (Figure 1a) is formed by: Electrical Panel containing a Siemens S7 1200 PLC. The robot control and Cognex camera are networked via Profinet communication protocol. For the I/O control, there are 16 digital inputs and 16 outputs, all available in terminal blocks, considering 3-wire sensors and 24 Vdc coils. Safety is provided by a small category 4 light barrier and a safety relay that sends signals to the robots. Specified a box with emergency reset buttons, barrier reset, cycle start, cycle end and also a Wireless Switch to enable the use of a Tablet as an HMI. The KUKA Robotic Manipulator is Industrial Robot model Agilus KR 6 R900 six, with 06 (six) spatial axes, maximum reach of 900 mm, repeatability of 0.02 mm, maximum load capacity of 6 kg and KRC-4 Control System (compact). The peripherals are: SmartPad with 7 meters long, Interface X51, I/O board with 16 inputs (24Vdc) and 16 digital outputs (24Vdc). Power supply for signals from I/O boards, maximum output 24Vdc/4A. KRL programming language and communication via Profnet (master). Dedicated softwares are: Gripper & SpotTech 3.1 Software, Micro EMD Mastering Set, Profnet 3.1, Work Visual 6.0, Load Determination and Remote Service. The YASKAWA MOTOMAN Cell (Figure 1b) is formed by: Electrical Panel containing a Siemens S7 1200 PLC. The robot control and Cognex camera are networked via Ethernet IP communication protocol. For the I/O control, there are 16 digital inputs and 16 outputs, all available in terminal blocks, considering 3-wire sensors and 24 Vdc coils. Safety is provided by a small category 4 light barrier and a safety relay that sends signals to the robots. Specified a box with emergency reset buttons, barrier reset, cycle start, cycle end and also a Wireless Switch to enable the use of Tablet as HMI.

It is a classic application for robots and other manipulation systems widely used in processes where it is necessary to "pick up" a certain object, move it, reposition and deposit that object in a previously delimited space. In the cells where the robots from the manufacturers KUKA and YASKAWA Motoman are mounted, each robot will pick up an aluminum block positioned at a specific point on the support table (XY plane), raise this block (Robot Z axis) , will move this block to another previously determined point (XY plane) and will deposit this block (robot Z axis) in this new position. In our case, the main task is to manipulate the thickness measuring equipment in conjunction with a camera to perform a "teleoperated" operation. The robotic system will be responsible for measuring and storing the thickness in "elbows" of nuclear pipe. The grapple design is still under development in conjunction with the simulation. The measurement activities will be carried out during the "stops" of operation of the Angra-1 plant and will include inspection and measurement of approximately 100,000 points with a duration of 25 days.

2a 2b

Figure 2 – typical pipe sections to be inspected. 2a) Thickness Inspection; 2b) Surface preparation for inspection measurements.

According to NUREG nuclear standards, the specification of sensors, ultrasound measurement system, pipe diameter and type of carbon steel will be defined. Detailed studies of "measuring surface preparation (figure 2b)" will also be evaluated, as well as point marking and procedures for calibration and thickness measurement during turbulent flow (figure 2a). The claw design of the robot under development must contain the following supports for: gel reservoir, measurement transducer, scanning electronics and vision camera with dedicated lighting system at the time of image capture triggering. Table 1 shows the main groups of activities necessary to carry out to implement this project.

Table 1 – Main activities necessary to develop the robotic system for automated measurement of pipe thickness as required by the aging management programs to extend the operating life of Angra 1.

Step	Description
1	Preparation of the surface of the external piping to carry out the measurement, instrumentation, specification and calibration of the measurement system by point transducer type ultrasound and surface scan type ultrasound;
2	Advanced design of the robot claw, Cartesian positioning (X,Y,Z) of the robotic cell for automatic thickness measurement with teleoperation system
3	Vision system for orbital guidance (6D) of the robot by capturing the points or measuring the scan surface
4	Communication interface and intelligent data treatment according to industry 4.0 enabling technologies
5	Virtual commissioning in Siemens Process Simulate software through the "digital twin". Construction of the robotic system (subject to appeal approval

3. Project challenges and discussions

This conceptual project is under implementation and its challenges can be divided into 3 parts:

a) Perform measurement pipe wall thickness with the robot positioned outside the pipe, preferably on top of it;
b) Perform measurement of wall thickness on the right or left lateral sides of the pipeline;
c) Perform measurement of wall thickness on the lower position side of the pipeline.

The pipeline areas out of reach or impossible to access with the robot arms will be disregarded. To perform the measurements it is necessary to have information about how to conduct surface preparation, cleaning details, preparation of the instrument and sensors, application of glycerin in the contact area, force applied to the transducer in the measurement position (points and scanning area). There are limiting conditions to perform the inspection measurements. For instance, to measure axially thin parts that are not vertical to the surface, the area should not be too small, otherwise the error measurement can be high. For curved surfaces of steel like materials, such as most of the pipe walls of the Angra-1 nuclear power plant, the radius of curvature must be greater than or equal to 1 cm, and the wall thickness must be greater than or equal to 3 mm.

The communication interface must analyze the data from the first measurement and if the measurement values of the thickness points present "problems", the communication system shall issue a "warning" and perform the second measurement using a more qualified scan of the surface. After the creation of the digital twin with all the physical and mathematical characteristics of the problem, as well as their restrictions, the virtual commissioning will be started in order to test and validate the prototype concept and the solution for building the robotic cell.

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