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Development of a prototype ROV for underwater inspections in the IEA-R1 reactor pool

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1. Introduction

The IEA-R1 reactor is a pool-type reactor, being the first research reactor in Latin America, inaugurated in 1957. Its fuel is enriched uranium, and it uses water as moderator, coolant, and shielding [1] [2]. This reactor is installed at the Instituto de Pesquisas Energéticas e Nucleares (IPEN), and in 2002, it obtained ISO 9001 certification, designed to operate at a maximum power of 5MW. Initially, this reactor operated at 2 MW, and today it is operating between 3.5 and 4.5 MW, with the aim of producing radioisotopes, irradiating samples for various purposes, and producing radioactive sources for industry and medicine [3] [4].
In order to find solutions that reduce human exposure to these environments during inspections, which are becoming increasingly commonplace and complex, with the aim of ensuring the operation of systems and preventing failures, corporations and institutions have begun to invest in the development of robots to be used in nuclear power plants [5] [6].
The application of underwater vehicles in the industry is becoming as widespread as their use in the marine environment, and much progress has been made in the development of new technologies for the nuclear sector [7]. According to CARMINATTO and CIONGOLI, countries like China, South Korea, and Japan are the ones that invest the most in underwater research involving technology applications in the nuclear environment [8].
Remotely Operated Vehicles (ROVs) are mobile, unmanned teleoperated robots used exclusively in aquatic environments, which are constantly manipulated by a pilot or operator who remains safely on the surface. The underwater vehicle is continuously connected to an operations module via a cable, called an

umbilical, which allows bidirectional communication between the components submerged with the vehicle and the operator on the surface. The controller sends the necessary commands to maneuver the vehicle, which in turn, sends images to a monitor on the surface, forming an underwater visual inspection system [9]. Visual non-destructive testing is a common practice for compliance monitoring in the industrial area, and underwater visual inspection with ROVs is one of the techniques used to monitor the conditions of submerged structures [10], being the only feasible method in underwater environments of nuclear power plants [2].

The present work aims to present the preliminary results of an underwater visual inspection conducted in the pool of the IEA-R1 research nuclear reactor, using a prototype ROV developed and built by the authors.

2. Methodology

An ROV is an integral part of a system composed of the vehicle itself, the umbilical cable, a control module, and a power source. For the purpose of understanding, the term ROV will be used to refer to the complete system, and in this prototype, it consists of a video camera, 3 thrusters, and illumination (Figure 1).

For the operation of the developed ROV system, programming was carried out through an Arduino microcontroller, and the code was written in Arduino IDE software version 1.8.19.

In addition to hardware and software integration, there are two more challenges to be overcome: the waterproofing of the components that will be submerged and the radioactivity in the water of the reactor pool, which can interfere with the operation of electronic components.

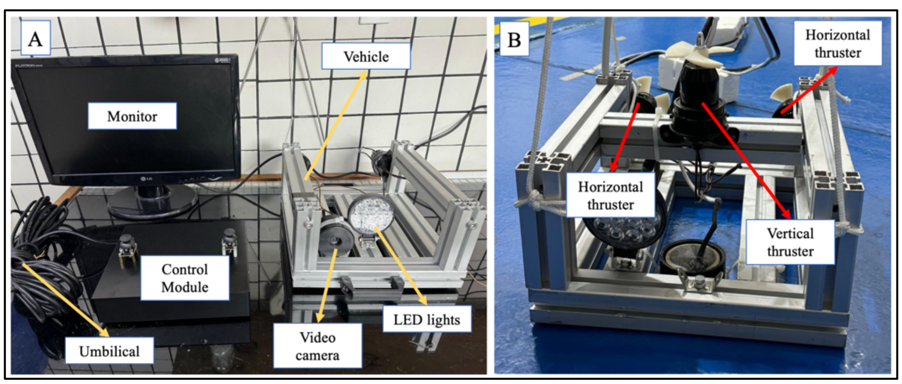

Figure 1: A - ROV system on the workbench for installation and adjustments. B - ROV ready for experiment in the IEA-R1 reactor pool.

The pool area was divided into four sectors with characteristics related to proximity (distance) from the reactor core, as shown in Table I and Figure 2.

Table I: Characteristics of each pool sector.

Sector	Distance	Sector	Distance
A	6,0 m	**C**	1,8 m
B	3,9 m	**D**	0,9 m

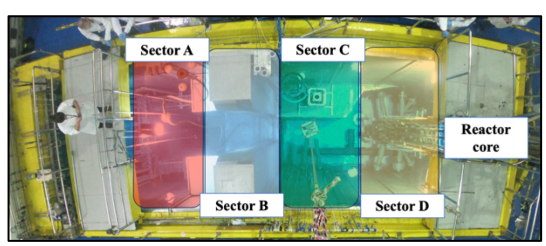

Figure 2: Sectors of IEA-R1 reactor pool.

3. Results and Discussion

Because it is a prototype of an ROV that, when completed, will be used for underwater visual inspections for preventive and corrective maintenance of the IEA-R1 reactor pool, the experiments were conducted with the reactor inoperable for, at least 48 hours, a scenario similar to what should be encountered during official underwater inspections.

Five experiments were conducted, consisting of the complete immersion of the ROV prototype inside the IEA-R1 reactor pool to verify two factors (functionality and waterproofing) of the following installed and tested components: camera, illumination, and thrusters (the latter composed of the integration of motor and propeller).

In sector A, further away from the reactor core but in the area near the storage of spent fuel, the camera, lighting and thrusters worked properly throughout the depths of the pool. The camera experienced weak radiation interference at depths between 3.0 and 5.0 meters, due to the proximity to the spent fuel. However, the interference was minimal and temporary, not causing difficulty in visualizing the structures and returning to normal image when moved away from those depths.

In sector B, near the pool gate opening, the components worked properly and without interference throughout the pool's depths. The same occurred in sector C, which is 1.8 meters away from the reactor core.

In sector D, less than 1.0 meter from the core, the lighting and horizontal and vertical thrusters worked properly at all depths, including the deepest areas of the pool. However, the video camera worked perfectly at most depths but exhibited image interference from approximately 6.0 meters to 8.0 meters. It's worth noting that the reactor core is installed at a depth of 6.89 meters.

In all points where radiation interference was present in the video camera images, although easily noticeable, the anomalies did not hinder the visualization of the submerged structures, and there was no permanent damage to the component during the time it was exposed.

In all sectors and depths, the waterproofing of the lighting and thrusters showed no defects. Regarding the camera, there was a failure in the resin sealing process of its waterproof housing, and at a depth of 5.0 meters water penetrated through the resin, causing flooding of the system. The component and waterproofing method were altered, and there were no subsequent failures after this event.

In Figure 3, some frames obtained from the recordings during the experiments at the IEA-R1 reactor.

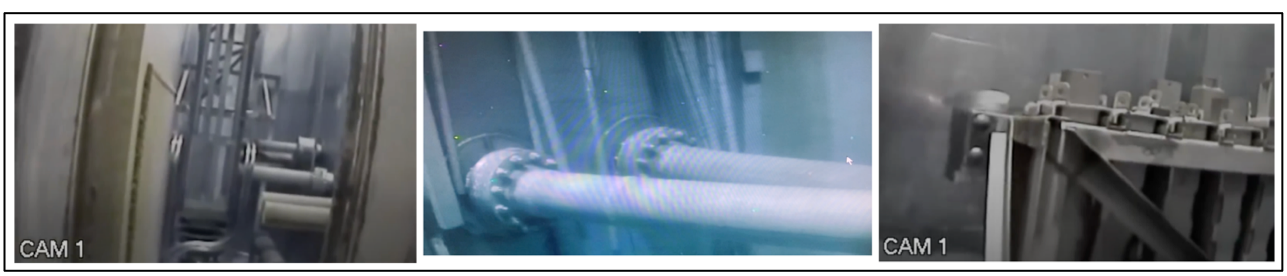

Figure 3: Images obtained from the recording of the video camera during experiment in the IEA-R1 reactor pool.

4. Conclusions

The ROV prototype is undergoing refinement and component alterations as part of an ongoing master's project at the Instituto de Pesquisas Energéticas e Nucleares. However, its current version with a 780-line video camera, LED lighting, 2 horizontal thrusters, and 1 vertical thruster has already proven to be efficient

in conducting underwater visual inspections.
Adjustments are necessary to improve the ROV's performance and to enable the acquisition of precise data and higher-resolution images. For example, a camera with vertical and horizontal movement could facilitate capturing better angles and positions depending on the structure being inspected.

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