Robotics Applicability for Routine Operator Tasks in Power Plant Facilities

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Abstract

There has been a growing interest in adopting autonomous robots to perform routine tasks in facilities management. The goal of facility management is to ensure that the facility performs to design standards. Currently, the cost of maintenance and operations of a facility over its life cycle is often more than the initial cost of construction. One of the reasons for these phenomena is the cost of repetitive but necessary tasks. Particularly for power plants, such repetitive tasks like routine operator rounds to check for leakages, dripping, gauge readings and turning of valves require a significant number of personnel who are exposed to a certain amount of health risk due to the nature of the facility aside incurring basic costs for remuneration and health benefits. These tasks can be automated and carried out by autonomous robots in collaboration with humans to drive down the risk and incurred costs significantly. Our study proposes a solution to routine operator task of checking gauges of machines within a power plant to monitor performance using an autonomous robot-based system that can autonomously navigate to spaces by estimating the reading from gauges to monitor performance and give reports to basic operator round tasks using the Building Information Model (BIM), Robot Operating System (ROS), Computer vision algorithms, a mobile robot and our designed algorithm. Our proposed solution in this study can act as a blueprint for further research to provide more efficient solutions in the maintenance and management of a power related facilities.

Keywords – Robotics; Facility Management; Routine Operator Task

1 Introduction

With the advancement of technology, the need of robotics application in facility management has been increasing for human and work environment safety concerns. Tasks of facility management are different than the tasks generally done by industrial robots as the facility management environments are more dynamic, and less predictable (Parker & Draper, 1998). The objective of the use of robots in nuclear power plants is primarily to avoid human exposure to harmful environmental conditions such as high radiation, temperature, and humidity, in which autonomous systems are required to function. Automation in facilities management can be advantageous in nuclear industry for early detection of adverse conditions by routine surveillance and inspection, withstand extreme conditions to decontaminate radiation, and high efficiency in doing repetitive tasks. Some of the repetitive but necessary tasks are routine operator rounds to check for leakages, dripping, gauge readings and turning of valves. In a power plant facility, personnel doing such repetitive tasks are exposed to certain health risks, which demands basic costs for remuneration and health benefits. Application of robotics for routine operator tasks, whether fully automated or semi-automated, can significantly drive down the risk and incurred cost. Accidents based on human errors in performing day to day operations can be lowered with the use of robots. In addition, automation can also provide as a solution to labor shortages for jobs under radiation. All of these benefits of automated system for routine operated tasks factor to more cost-effective operation, increased overall productivity and improved performance of a nuclear power plant.

2 Robotics in Power Plants Facility Management

Nuclear facility operation and management system comprises of individual tasks and groups of tasks to be performed by either human, machine or a combination of both, in complex systems (IAEA, 1992). And, out of many activities, the area of routine operator task is one where a conjunction of robots and humans can be valuable. The key rationale of robotic applications in this realm is to enhance the operation of tasks which are routine, lengthy, require high accuracy & consistency, and involve high risk to humans (IAEA, 1992). A combination of human and automation can be beneficial in all three categories of routine operations- nuclear power reactor operation, power distribution & dispatch, and power plant operation-to make judgement, decision, and execution (Bureau of Labor Statistics, 2021). Some examples of these routine operator tasks include steam generator examination, tube leak plugging, dripping, gauge readings and turning of valves (IAEA, 1992). Robots, of various types, have been used in various applications in facility management to reduce the task completion time, to reduce health hazards, to improve safety, and to improve availability (Parker & Draper, 1998). Like, any specific task operation in the facility by specific human workforce, it is challenging but achievable in future to have robots with such intelligence to complete tasks in unforeseen situations (Iqbal et al., 2012). However, current practices in nuclear power plants are generally revolve around the idea to have a particular robot for a specific task. Suitable training for operators, and the development of multidimensional simulation models to operate robots on specific environment are the keys in achieving robotics implementation for facility operation and maintenance (Tochilin et al., 2021). This paper is focused on a specific scenario of nuclear facility routine operator tasks which is explained in the section 4.

3 Aim and Objectives

As developed and developing nations perfect plans to automate more tasks in response to the needed transformation into the digital age. More tasks are expected to be robotized freeing up humans from tedious activities and harmful job situations such routine operator tasks in power plants to increase productivity and efficiency. Our study aims to contribute to this body of knowledge by proposing an approach to robotize routine operator tasks using Building Information Model (BIM), Robot Operating System (ROS), Computer Vision, a mobile robot, and our designed algorithms. Specifically, our study will (1) create a robot-based system that enables autonomous navigation, object detection, data collection and monitoring of power plant equipment, (2) autonomously monitor and estimate the gauge reading of power plant equipment at scheduled routines, (3) create an inspection report of estimated reading, and (4) test the performance of the system in a simulated environment of an educational facility using Gazebo and Robot Visualizer (Rviz). Our proposed solution in this study can act as a blueprint for further research to provide more efficient solutions in the maintenance and management of power and nuclear related facilities.

4 A Scenario of Routine Operator Tasks

There are different areas such as a nuclear reactor, auxiliary area, turbine generators area, fuel area, controls area, with multiple components in a nuclear facility management (Figure I).

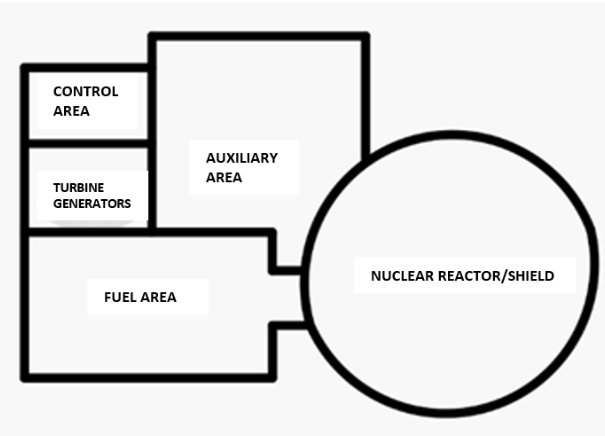

Figure I: A typical area plan scenario of a nuclear facility.

In this research, we have developed a scenario for our robot that can work on a specific room of turbine generators area that houses turbine, generator, condenser, condensate pump, and feed water pump. This room contains different valves and gauges that are directly connected to reactor building (Figure II). In this scenario, the general current practice of routine check of different pumps, their pressure, temperature, leaks, and vibrations is done by the field operators and they give feedback to the license operator who typically works from the control room. In the light of this scenario, performing these tedious routine tasks involves possible challenges of hazard risk, time inefficiency, inaccuracy, and large labor hours and cost. Therefore, in our proposed work model, a robot can work in conjunction with an existing operator to assist in daily gauge reading tasks. However, not all judgements will be made by this robot. To perform the given task using a robot, it is an important ability to create autonomous navigation algorithms that is based on the information from the operating setting (Wang et al., 2018). We have envisioned a robot with vision capacity that can follow the assigned path remotely and walk into this area, capture images of the different gauges, post-process the image, determine the temperature and pressure of the values, and, finally, send to the control room where the ultimate decision will be made by the control staff. This robot, which will work in a loop with license operator, can also be useful in performing tasks in confined space and high radiation field. As the nature of operation in this scenario is also similar to other facilities, for example-water utility facility, this robot can be incorporated in such environment for everyday activities to achieve more overall efficiency.

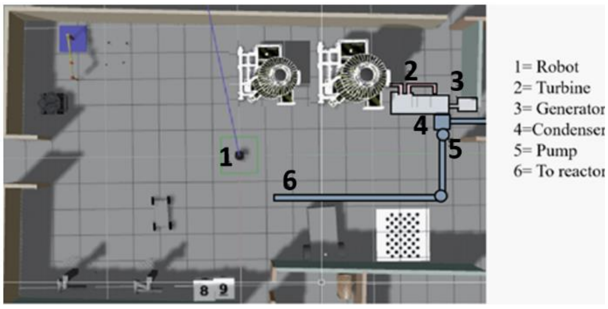

Figure II: A scenario room inside a turbine generator area of a nuclear facility.

5 Methodology

The building used in this study for the simulation environment to replicate the scenario of a turbine generator area in section III is a laboratory of an educational facility with machines that require a gauge reading to monitor their performance during operation. Our set objectives were achieved by first recreating the model of the laboratory in Gazebo world from its Building Information Modeling 2D plan. A world in this context represents a space or environment created in Gazebo for simulation of real-world scenarios. This plan was passed through a Pgm_map_creator algorithm (https://github.com/hyfan1116/pgm_map_creator) to create a 2D map as shown in figure III containing the foot print of all objects and elements in pgm format readable by Adaptive Monte Carlo Localization (AMCL) algorithm (ROS.org, 2020) which is used for autonomous navigation and localization of the robot and its environment features. Having successfully integrated the laboratory map into AMCL, an executable script was written to ensure our mobile robot navigates to predetermined coordinates with proper orientation within the map ensuring that the robot can capture the gauge of the machine in its view at every routine check from that position.

Subsequently, a machine (Ponjet Industries, 2020) and gauge (Cjanezich, 2014) models were downloaded from https://3dwarehouse.sketchup.com and attached to each other which is placed in an appropriate position in the Gazebo world. Through programming scripts, A fake pressure is then autonomously simulated in the machine and gauge forcing the gauge needle to imitate real world gauge needle movements. This is followed by spawning and localizing the model of the mobile robot in the simulated world and map generated earlier. Probabilistic-based guesses of the current position of the robot in relation to the map are continuously made during navigation using the AMCL algorithm, LiDAR information, odometry and inertial sensors. It is noteworthy to mention that errors from sensors measurements will accumulate if left unchecked during navigation hence the need for the continuous calculation of the robot's location during navigation in the world.

For the robot to perform monitoring task, a command is issued through a ROS node that contains preset navigation goals. A ROS node is an executable set of instructions contained in a file that runs within the robotic application. This command instructs the robot to avoid obstacles and autonomously navigate to certain positions and orient itself to a certain view of the world. This command can be manually issued by running the ROS node script or automated through launch files. The autonomous navigation ability of the robot is provided through a set of algorithms known as Navigation stack together with AMCL within the ROS ecosystem and the building floor plan. The process involves the robot accurately localizing itself and its target destination, which is followed by planning and mapping of the best route to reach the target destination with preference to the shortest distance to that target destination. The best route planning and mapping is continuously repeated by the robot to find a way around the obstacle for an alternative route in the event of an unforeseen obstacle suddenly appearing blocking the initially mapped route either permanently or temporarily like a standing person or object.

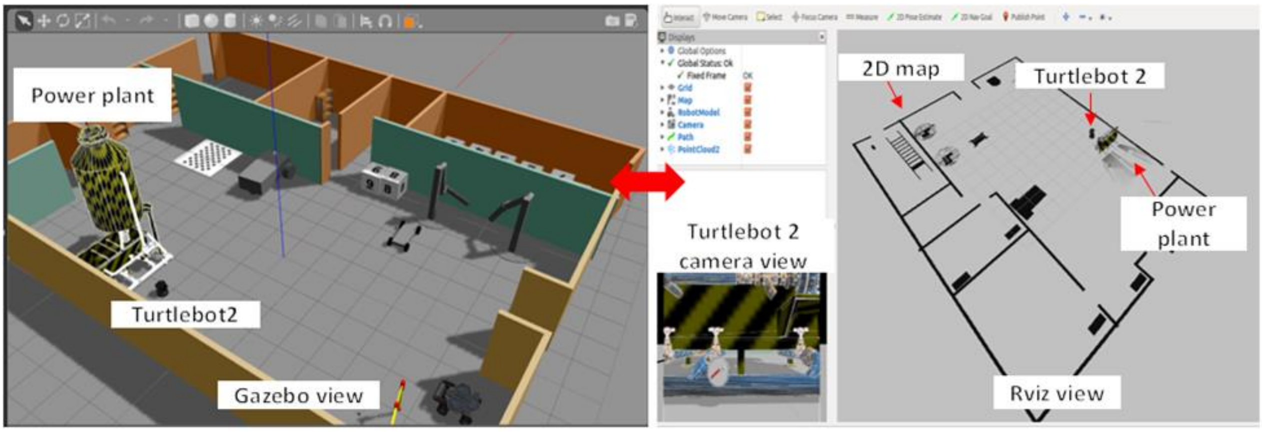

Figure III: Showing the case study set up and robot looking at the model plant machine.

On reaching the destination, the inspection activity begins with the robot taking a picture (image) of its view at the pre-set location and orientation through its camera which places the gauge at approximately the center of the robot's camera view. This image is then processed through Computer Vision (OpenCv) image detection algorithms to crop out predefined area of the picture that contains only the gauge (the body and needle position) face. The image recognition of the gauge face relies on the fact that the cropped image guarantees that the needle, which is colored red, will be approximately centered in the middle of the image and protrude through one of the four edges as shown in figure IV.

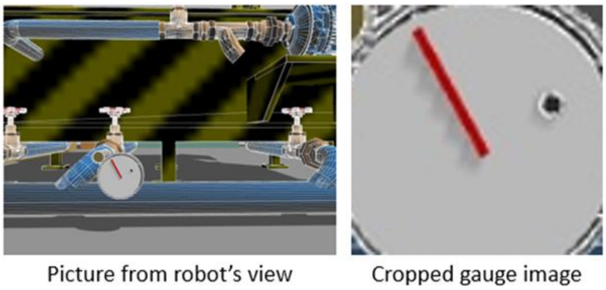

Figure IV: Side by side picture taken by robot and the cropped section for image detection.

This image is saved to disk, and the image recognition algorithm is called. The algorithm is written as a stand-alone application with the sole goal of calculating the pressure value from the gauge. The application is passed the file name of the image and loads this image during initialization. Once the cropped image has been loaded, the height and width parameters are obtained from the image. Nested for-loops are used to iterate over all the pixels in the image. A check is made to determine the pixel color, with all red pixels accumulated in a list.

The principal idea is to determine the angle of the needle by sampling the pixels that make up the image, especially along the edge of the image. After all red pixels have been determined, the edges of the image (top, bottom, left, and right) are sampled to see if they are included in the red pixel list. These pixels are retained in a red-edge-pixel list. When an edge has been identified, the pixels at the opposite side of the needle are determined. They are the red pixels that are the farthest from the edge being examined. Knowing the coordinates of the pixels at the two sides of the needle allows a simple arc tangent function to be used to determine the angle of needle. Then an angle-to-pressure conversion is made to obtain the corresponding pressure value.

6 Case Study

In tandem with the study objectives, a part of the Peter Kiewit Institute (PKI) educational building in Omaha, Nebraska BIM model containing the laboratory was used to create the scenario environment envisioned in section III of our solution in Gazebo and Rviz packages from the ROS ecosystem alongside the AMCL algorithm. The BIM model created an underlay to recreate the world in Gazebo environment and infuse the machine plant model alongside other relevant objects to mimic the turbine generator area scenario. The Gazebo package in ROS provides a platform to simulate real world environment and scenarios ensuring that accidents and damages that may occur during real world testing is avoided while Rviz gives us more than a sneak peep at what is happening in the "brain" of the robot during task or command execution. Both are powerful visualizers that we employed in our work to checkmate and observe the performance of our design.

A model of Turtlebot 2 mobile robot was used in our simulation. We initiated the case study by spawning the robot in the simulated world and issuing a set of commands via ROS to the robot autonomously by running a launch script that includes all the necessary commands. This script is responsible for starting previously described ROS nodes and other commands such as the navigation stack, AMCL algorithm etc. orientates itself both in Rviz and Gazebo by doing a couple of turns about its centroid to identify its position, map out its destination in relation to obstacles(objects) on the map, navigate to its target destination and orientates itself again to look at the gauge as shown in figure V, takes a picture and then run it through OpenCV algorithm required for the robot to perform its tasks. On receiving the commands, the robot starts up Rviz and localizes and to crop out just the part containing the gauge as shown earlier in figure IV, apply color detection algorithm and calculate the position of the needle based on our algorithm to provide an output of the converted gauge readings.

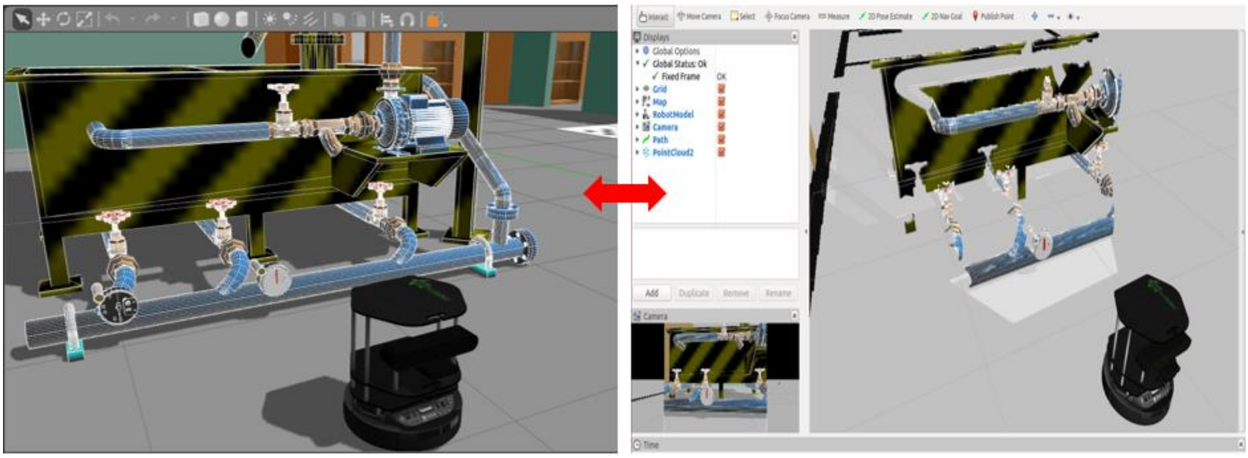

Figure V: Showing the robot looking directly at the gauge to estimate gauge reading.

These readings are now presented inform of an inspection report (see figure VI for a sample of such report) with a clause in the system to issue warnings in case of anomalies such as beyond normal or poor performance of the equipment. This process is repeated thrice in this case study with one of the readings purposely manipulated to test the occurrence of an anomaly. The report from this routine monitoring can be used by plant managers to make an informed on the go decisions about their facilities rather than waiting for personnel to report in the findings of their routine inspections.

```
Image statistics
================
File:                cropped_image_5.jpg
Size:                100 x 100
Number of channels:  3
Data type is:        unsigned char

A total of 154 red pixels were found.
A total of 0 top edge pixels found.
A total of 0 bottom edge pixels found.
A total of 0 left edge pixels found.
A total of 3 right edge pixels found.
Right edge point present. Left most red point is (45, 43).
deltaX and deltaY = 55, -16
deltaX and deltaY = 55, -17
deltaX and deltaY = 55, -18
The needle 3 values are: -0.283096   -0.299776   -0.316286
The calculated average needle angle is: -0.299719 radians.


The calculated pressure is: 89.6936
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Figure VI: A sample of the inspection report generated from estimating gauge reading.

7 Conclusion

Our study proposes a solution for a routine operator task, specifically, monitoring and checking the performance of machines in an ideal power plant setup through gauge readings. We developed and tested a robotic solution that can autonomously infer the performance of machines by the readings of its gauge in model power plants or facilities such as boilers, water, electrical and nuclear plants that require continuous routine checks of their machines. Our design by extension, has the potential to eliminate the extensive use of workers allowing a mobile robot to routinely navigate autonomously to preset locations with a predefined orientation to estimate the readings of machines or power plant systems and monitor their performance, providing report of inspections and warnings in the event of an anomaly in the readings.

This solution is ready for real world testing based on the performance from the case study. It buttresses our thinking that robotic systems have the potential to replace present systems used in power plants and related facilities which are cost and personnel intensive. This solution also provides an opportunity to reduce the safety and health risk of humans working in these facilities. In all, this study acts as an ice breaker ushering in innovative ways and application of using robots in power plants for day-to-day repetitive operations and management.
In the future, we hope to extend this work to accommodate probabilistic based approaches as well as dynamic scenarios of power plant operations. This will aid our plan to infuse more capabilities beyond gauge reading and estimation into our robotic system leading to an enhanced application that is more robust to perform other routine operator tasks

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