UNIVERSITY OF BATH

Simulation of Spent Nuclear Fuel storage

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EE50236 Robotic Platform Engineering

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Contents

1-Introduction

The reprocessing of used fuel rod fell out of favour among major countries like USA, Germany and United Kingdom. At the same time, many countries have built nuclear power plants without the considerations for reprocessing of their own. As a result, storage of spent nuclear rod in wet or dry condition has become a prefer option prior to the disposal. For the wet condition, the spent nuclear rod resides in a water pool at the reactor. The wet storage uses demineralised water to cool the spent nuclear rods. As the reactor's pool capacity reaches the storage limit, dry storage condition solution become vital. Examples for the dry storage conditions are CANSTOR, containers made of concrete and containers made of steel. As the confidence in the dry storage condition grow, countries like USA and Germany gives the storage limits to 60 years (Lovasic, 2012).

Due to the growing interest in dry storage technology, we simulate the transfer of spent nuclear rod to a concrete cask using Coppiliasim simulation software. Further in the report, we acknowledge spent nuclear rod to rod.

2- Design Overview

Four Niryo robots navigates the rod across three walls and places the rod in a receptacle. For the simulation purpose, we assume navigating the wall means transfer of rod from one processing room to another. In addition, Gantry system moves the rod from a receptacle to a concrete cask while navigating through a wall. Due to the radioactive environment, we employ a line following autonomous bot which transfers the concrete cask to a storage unit.

The figures 2.1 illustrate the simulation environment overview and the figure 2 to figure 10 illustrates the simulation steps in a sequential order.

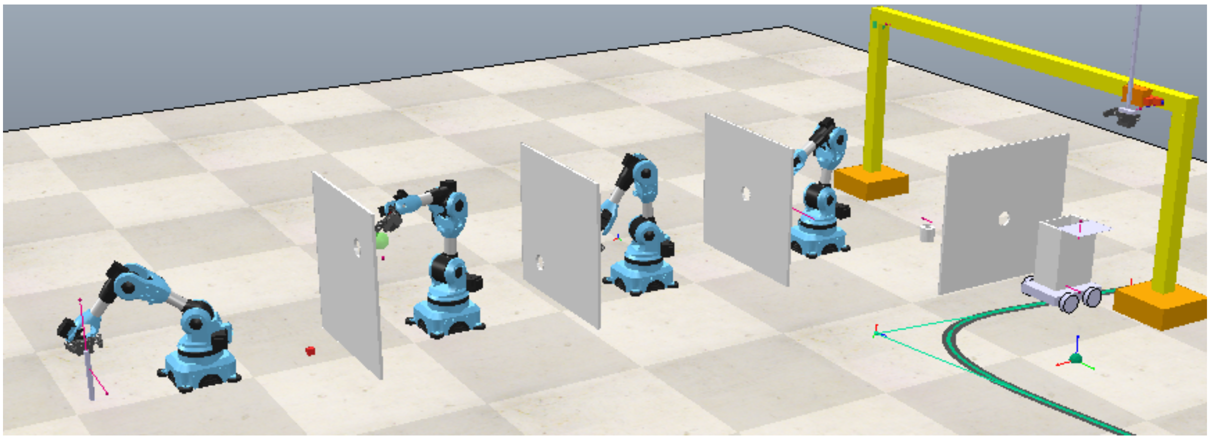

Figure-1 Simulation environment overview.

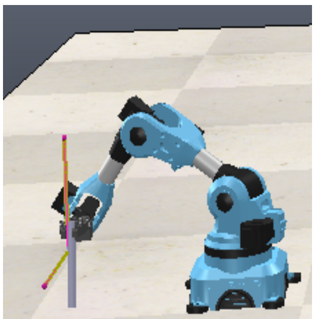

Figure-2 Robot1 picks the rod

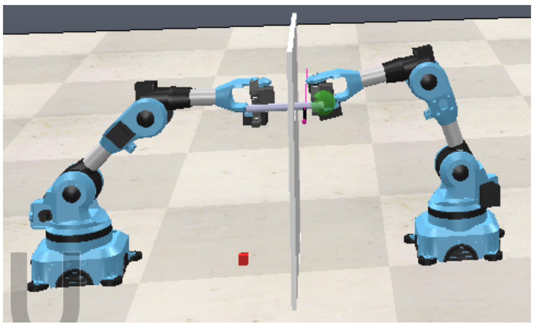

Figure-3 Robot 1 passes the rod to robot 2

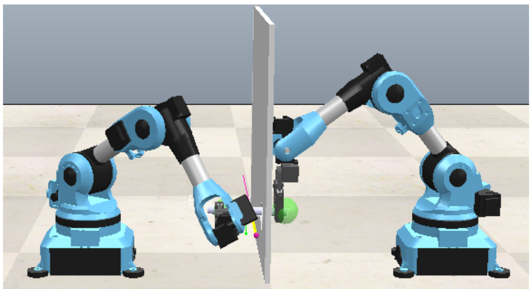

Figure-4 Robot 2 passes the rod to robot 3

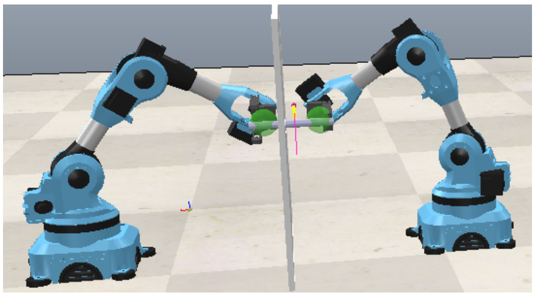

Figure-5 Robot 3 passes the rod to robot 4

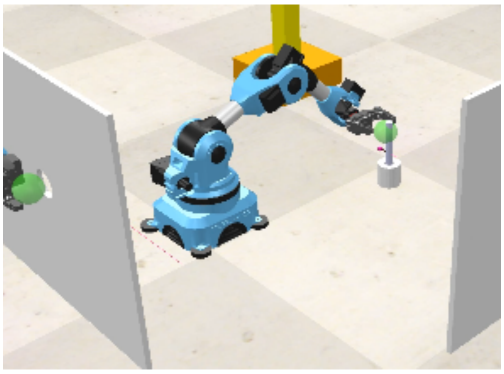

Figure-6 Robot 4 places the rod in a receptacle

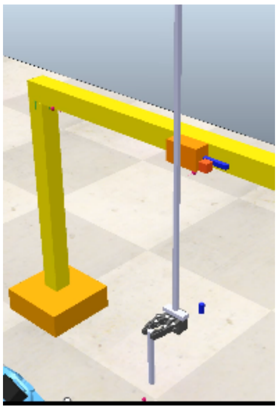

Figure-7 Gantry systems picks the rod from receptacle

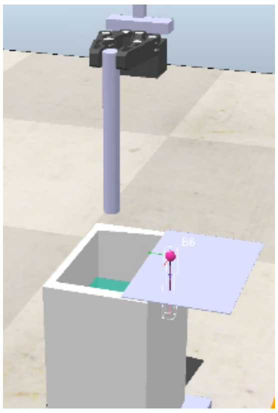

Figure-8 Gantry system places the rod into the concrete cask

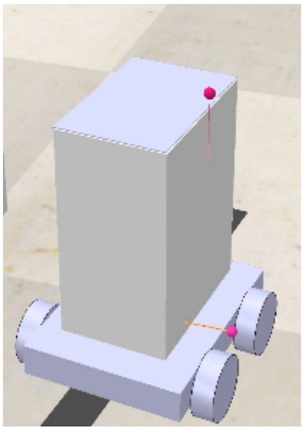

Figure-9 Concrete cask door closes

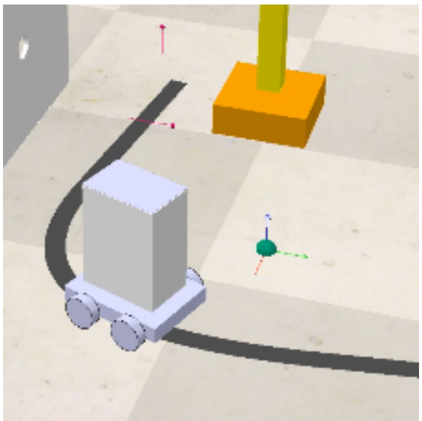

Figure-10 Bot drives to the destination using the path

3-Hardware design

3.1- Detecting the wall hole is clear of obstruction

Each wall has a sensor as shown in figure 11 to detect the wall's hole is clear of obstruction prior to the robot pass the rod to another robot. The sensor type is ultrasonic sensor because the ultrasonic sensor readings are less suspectable by the glossy and transparent objects and ambient light conditions (Omron, 2013).
The chosen sensor volume type is a ray due to its precision line. A precision line can detect object in a compact space compares to other volume types such as cone, disc etc.

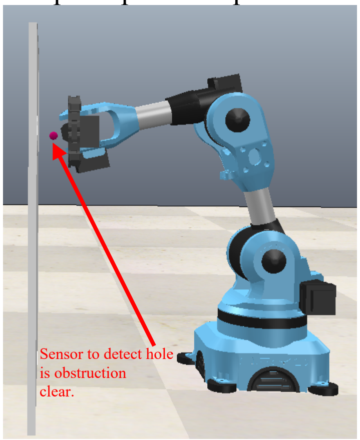

Figure-11 Sensor to detect the wall hole is clear of obstruction.

3.2- Detecting the rod presence at the pick station

Two sensors B1 and B2 as shown in figure 12 checks the rod presence at the initial pick position in respective to the pre-set robot coordinates. The approach allows the robot 1 to pick the rod while both sensors is ON. The sensors distance sensitivity is set to higher accuracy. The sensor type is ultrasonic and sensor volume type is ray. The sensor B2 check the rod position in the Y axis coordinates as well as the rod height. The sensor B1 checks the rod position in the X axis coordinates.

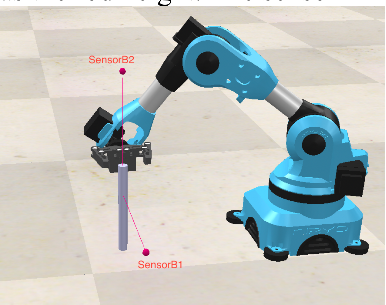

Figure-12 Sensor representation at the rod pick station

3.3- Algorithm for Niryo robots

The flowchart in figure 13 represents the algorithm which applies to all four robots with some exception. For the robot 1, the rod pick signal comes from the sensors as per section 3.2. The robot 4 places the rod in the receptacle as per section 3.4 and signal the gantry system to pick the rod.

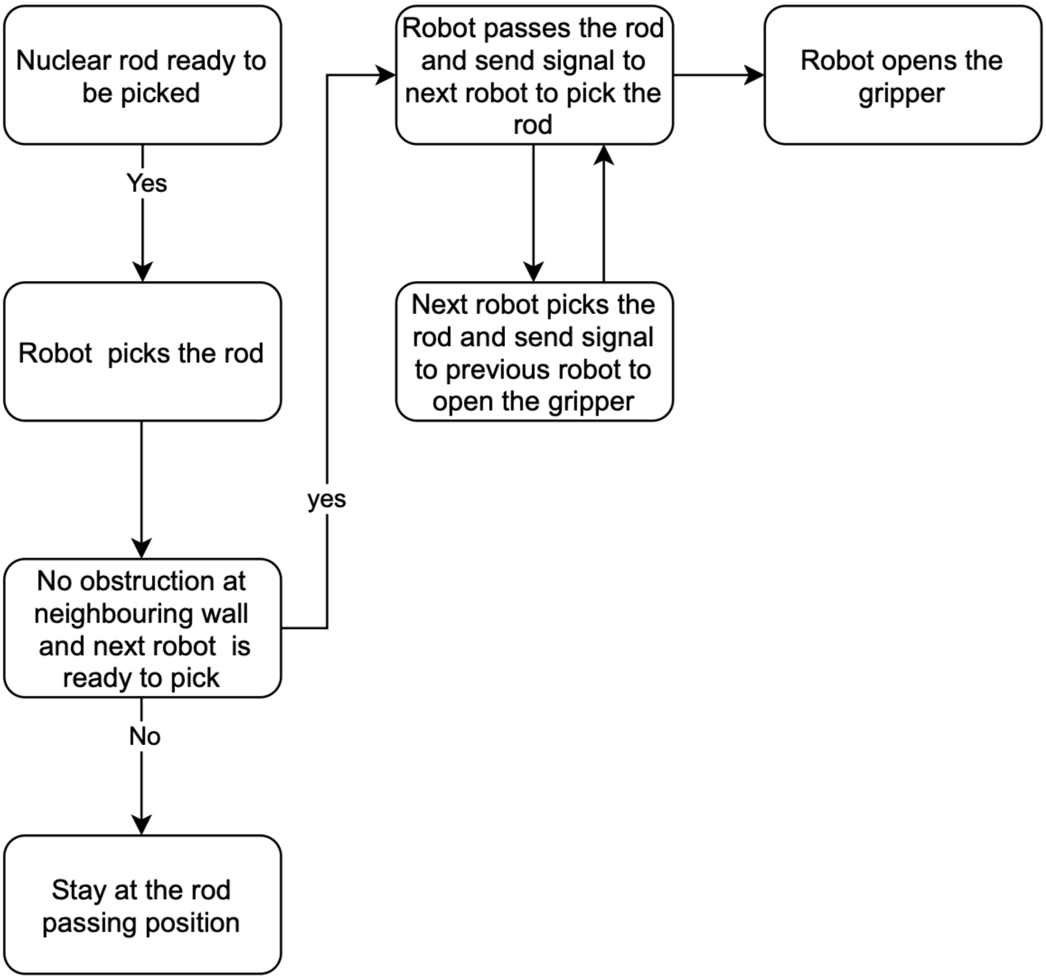

Figure-13 Flow chart representation of robot's algorithm

3.4- Rod receptacle

The rod receptacle as shown in figure 14 act as a rod placing station. For simulation purpose, we assume the rod receptacle is fixed to the floor. The receptacle has an ultrasonic sensor (B6) as shown in the figure 14 to detect the receptacle is empty to hold the rod. The receptacle hole diameter is 15mm since the rod diameter is 12mm. The 3mm gap will compensate for small place position inconsistency and enables the rod to stay at perpendicular to the floor without any slant.

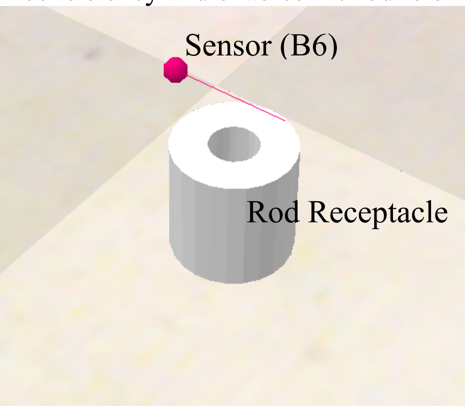

Figure-14 Rod's receptacle representation

3.5-Gantry system

The sensors YaxisLimit and ZaxisLimit as shown in figure 15 act as a limit sensor. Furthermore, the sensors can act a homing sensor for the respective joints since homing is necessary to set the joints zero position. The sensors type is an ultrasonic sensor. Detection at a considerable range allows the joint to stop with a smooth deceleration rather than a rapid deceleration which creates degradation to the joints overtime. As shown in figure 16, the gantry system employs two prismatic joints. Z axis joint allows the gripper to move along the up and down direction. Y axis joint enables the gripper to move along the left and right direction. The Gantry system employs Niryo robot's gripper to pick the rod. The flow chart shown in figure 17 represents the software architecture for the gantry system.

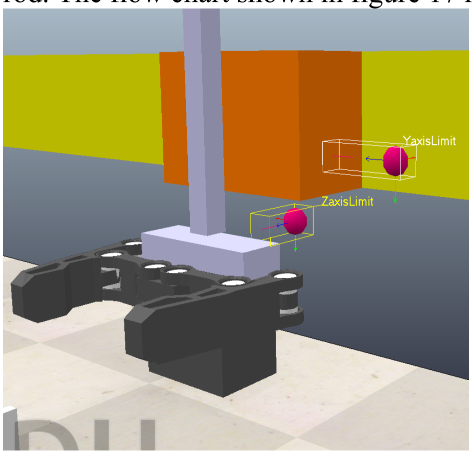

Figure-15 Representation of limit sensors

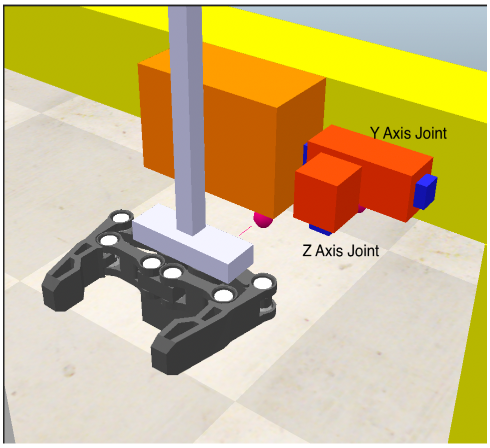

Figure-16 Representation of gantry system joints

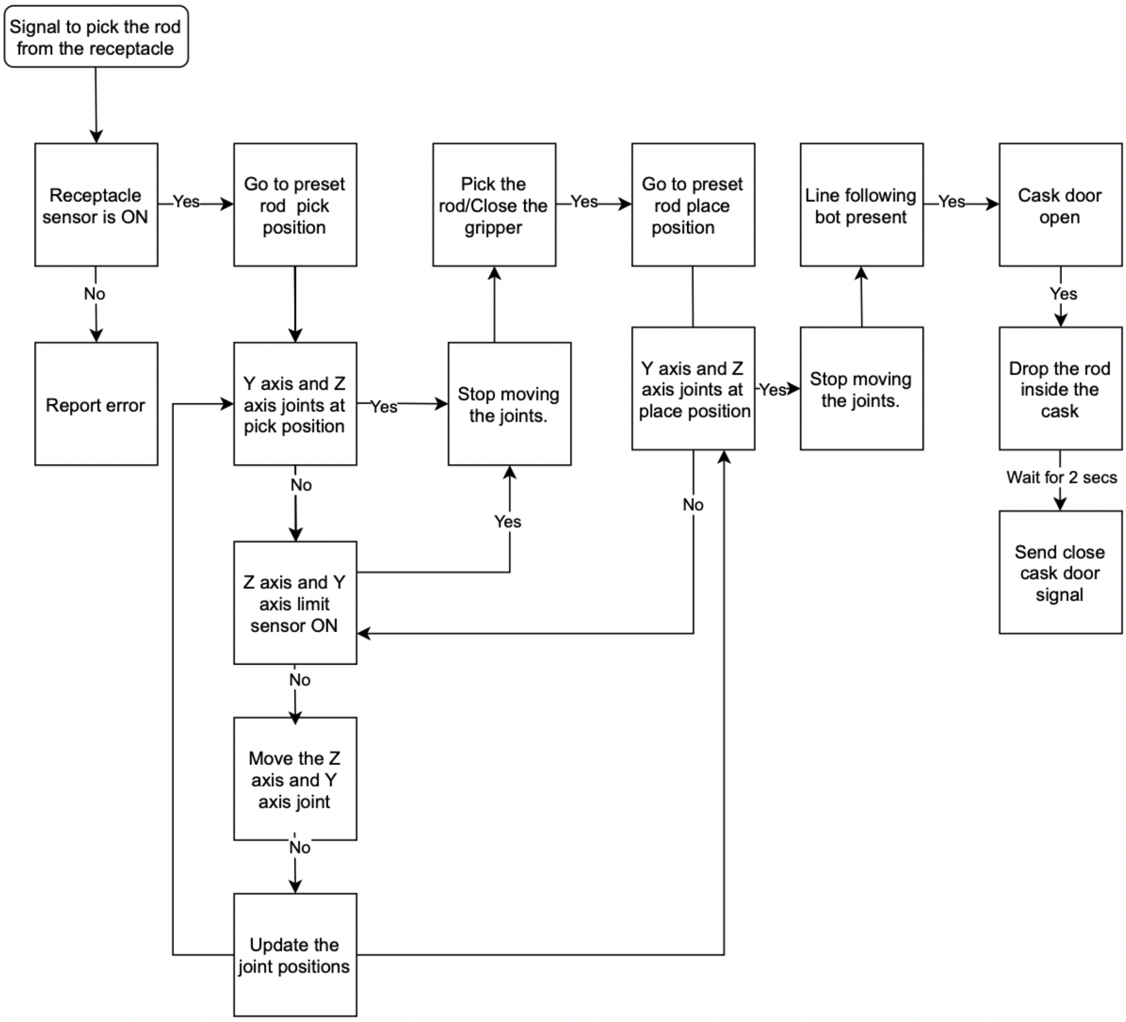

Figure-17 Flow chart representation of gantry system's algorithm

3.6 Line following bot

The cask employs prismatic joint to extend and retract the door. The sensor B8 (figure 18) is an ultrasonic type and the function of sensor B8 is to provide feedback on the cask's door open position as shown in the figure 18. The gantry system uses the feedback position to place the rod. In addition, sensor B8 acts as a limit sensor and a home sensor for the cask's door.
The sensor B7 (figure 18) utilises ultrasonic sensor to stop the bot precisely at the rod drop position. The bot uses three vision sensors as shown in figure 18. The vision sensor is facing the floor to detect the path. Each vision sensor employs single pixel and determines the average colour intensity of the acquired image. Through the reiterative test approach, the average colour intensity of the line is less than 0.5. As shown in the figure 18, the front wheels use revolute joints to move the respective front wheels and the back wheels use force sensors to move along the front wheels.
The vision sensor information helps to steer the bot along the path. The flow chart shown in figure 20 explains the software architecture of line following bot.

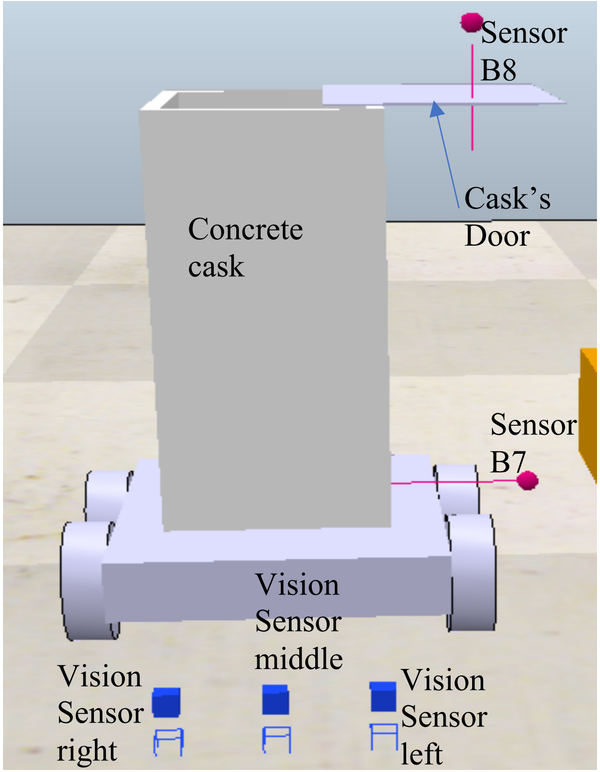

Figure -18 Representation of line following bot's features

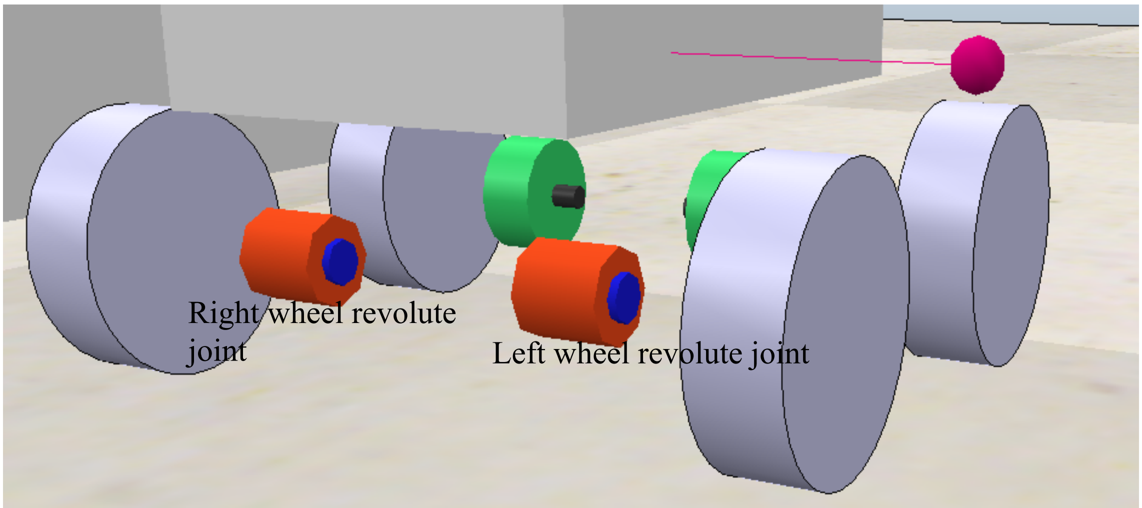

Figure -19 Representation of line following bot's joints

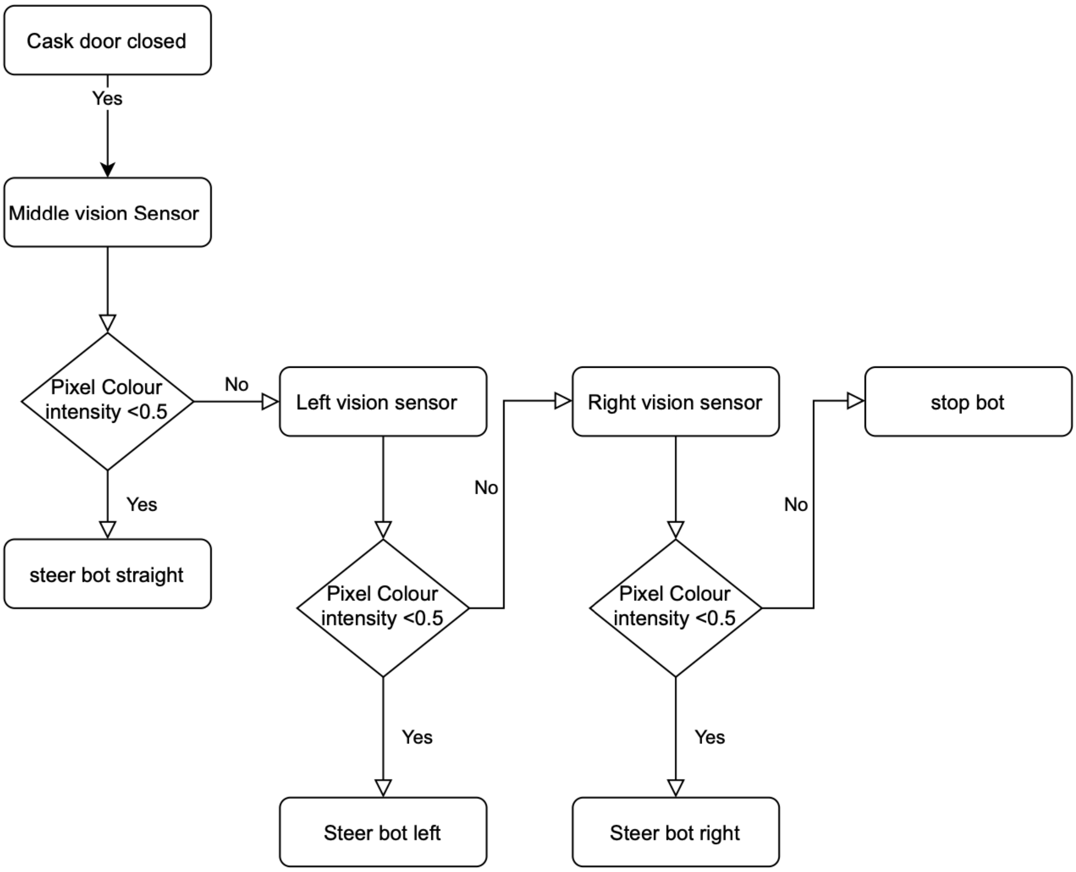

Figure-20 Flow chart representation of line following bot's algorithm

4-Simualtion Implementation:

4.1- Rod Morphology

As per the source (Buongiorno,2010), the physical rod height is 3600mm. However, the rod height in the simulation is 150mm. Simulating the rod as per the physical dimension causes the rod to droop significantly and causes problem while robots move the rod. Therefore, the rod height assumes to be 150mm.

4.2- Gantry system

For the simplification purpose, gantry system in the simulation uses prismatic joint to facilitate linear movements rather than using a servo with a timing belt setup as per the figure 21. For the simulation purpose, the author also assumes the gantry systems joints works with full accuracy and needs no recalibration since no deterioration due to overuse or aging.

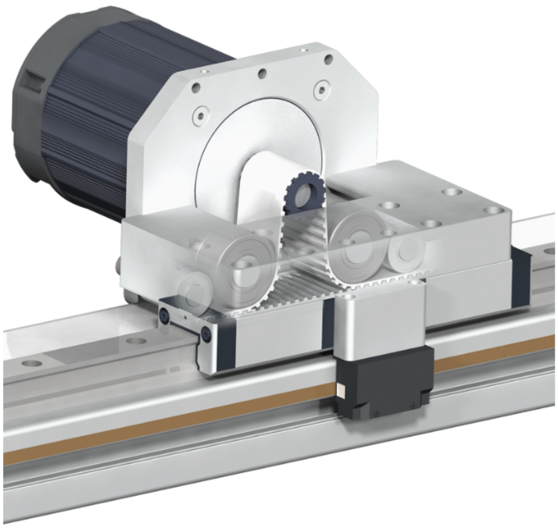

Figure-21 Representation of the servo with the timing belt configuration. (Bell Everman, 2015)

4.3- Simulation Environment

For the simplification purpose, we will assume the sensors and actuators in the simulation is not affected by the radiation, temperature, humidity, ambient light and other environment conditions. Furthermore, we utilise the sensor signals without the ON delay timer and OFF delay timer functions. However, in a physical world, the timer functions play significant role in eliminating false sensor readings due to various environment conditions.

5- Results and Discussion

5.1-Test approach with inverse kinematics

Path planning with inverse kinematics:

In the initial tests, robot has fewer intermediate positions between one point to another. The test result is shown in figure 22, the robot navigates to the wall hole in a curve path even though the all the joints are parallel to the wall hole and the robot fails to navigate in a straight-line path as shown in figure 23.

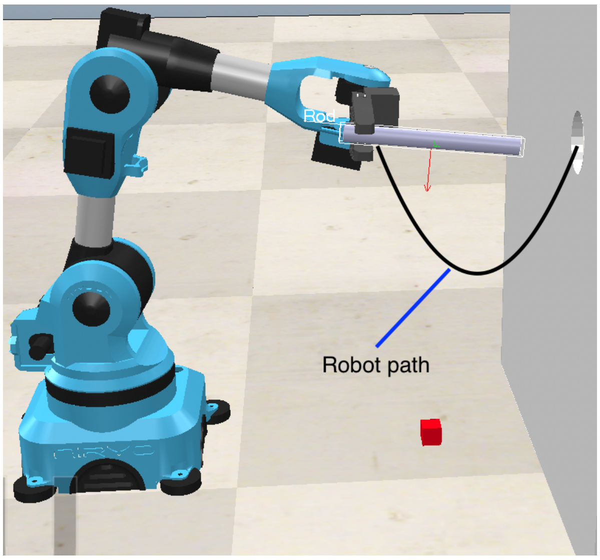

Figure-22 Robot performing a curve path

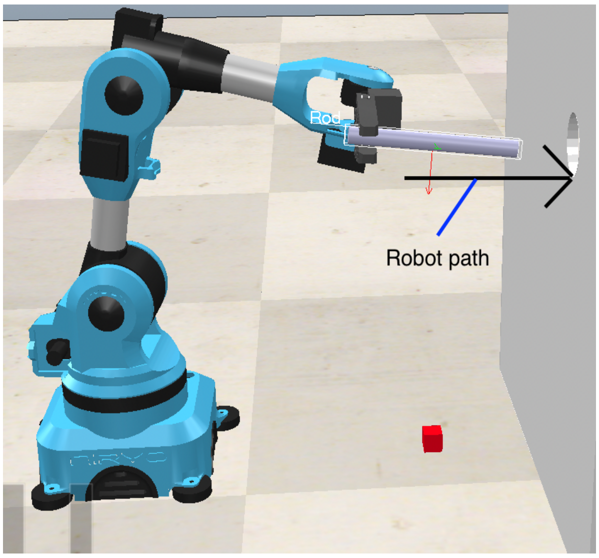

Figure-23 Robot performing a straight path

As a next test approach, the robot has intermediate points for 2cm interval, and the curve path is small compares to the initial test but large enough to hit the wall. For the next approach, we use intermediate points of 1cm and the result is the rod navigates through the hole without any obstruction. However, the robot does go in curve path but makes less arc as shown in figure 24. Therefore, similar approach needs for the implementation in a physical robot.

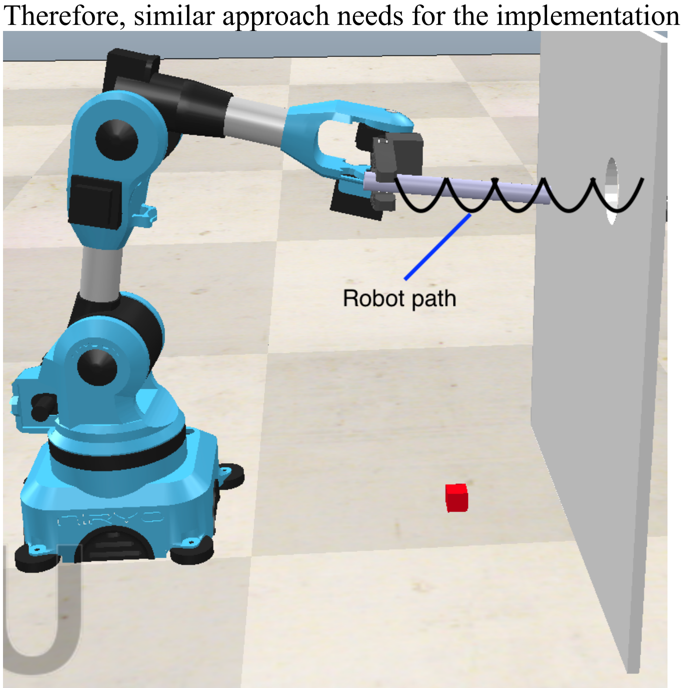

Figure-24 Robot performing a small curve paths

With the inverse kinematics approach, the robot takes between 20-40 seconds to settle in a position as shown in the figure 25 where the robot gripper in a parallel position closer to the wall hole. As a result, the inverse kinematics approach for four robot takes approximately 8 minutes to finish the cycle. The above result can prove to be a failure in a high-speed operation environment.
The author simulates the robot with a forward kinematics approach to attain a timescale for the robot to reach the position as shown in figure 25 using forward kinematics. The robot takes 5-10 seconds to reach the position shown in figure 25. It appears forward kinematics approach is an appropriate solution in a physical robot since the approach takes significant less time to finish a cycle and can perform higher throughput. As a contrary, use of vision sensor to guide a robot using forward kinematics can be difficult.

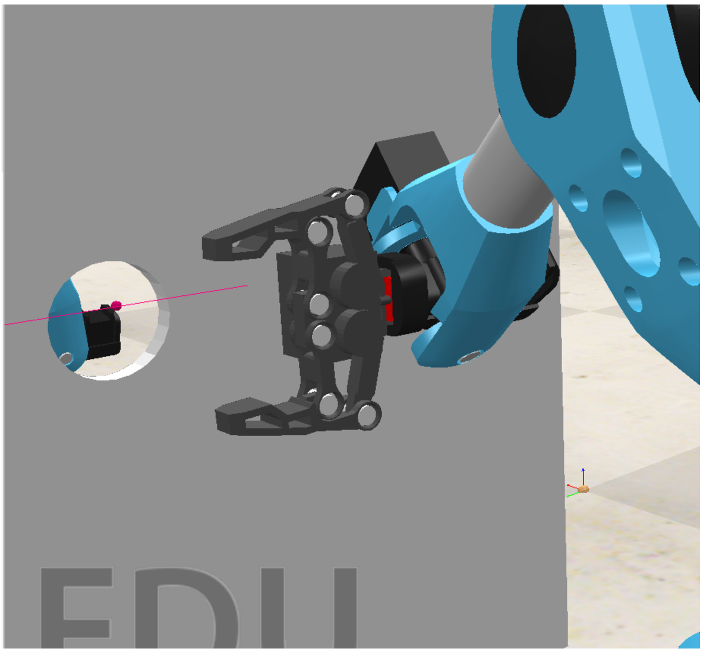

Figure-25 Robot rod pick position

5.2- Gantry system test approach

The gripper of gantry system in the initial test is shown in figure 26. The moving plate move towards the static plate using a prismatic joint and holds the rod. From the simulation test result, the gripper design holds the rod. However, the rod slips through the gripper while the gantry systems lift the rod from the receptacle. The reason for slip appears to be less friction between the rod and gripper plates. As a second test approach, the moving plate moves further towards the static gripper to hold the rod firm. From the test result, the rod slips again in a side direction due to the additional force from the prismatic joints. As a third test approach, the gantry system uses Niryo robot 's gripper as shown in the figure and the test approach is a success. Therefore, the gripper design for the rod needs to encapsulate the rod to eliminate the slip. Furthermore, the gripper for physical robot can be soft gripper (figure 28) which can provide additional grip and stability. As a contrary, soft robotics gripper approach adds pneumatic complexity.

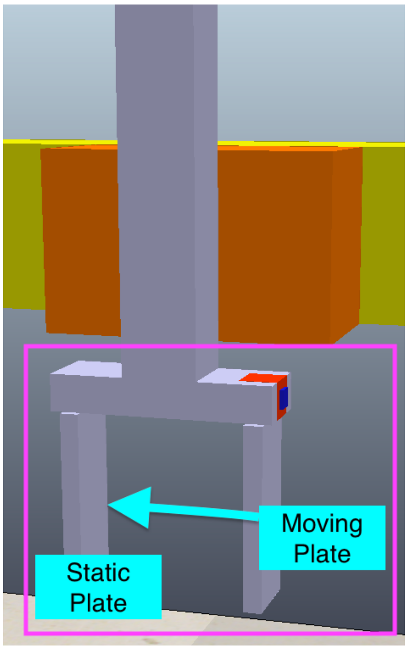

Figure 26- Gripper design 1

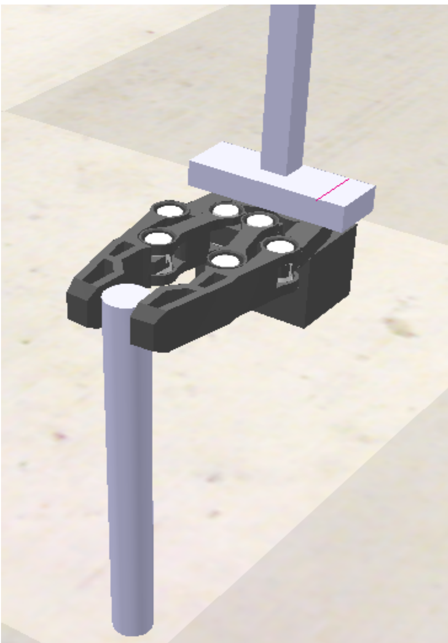

Figure 27- Gripper design 2

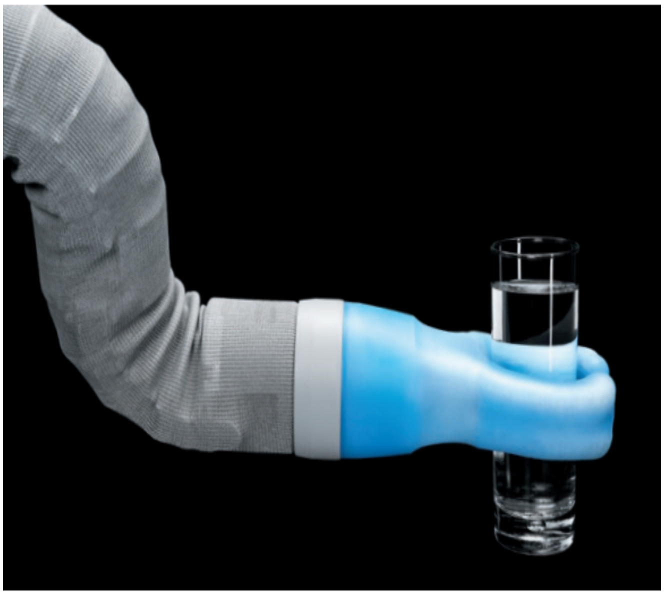

Figure 28- Soft gripper holding a cylindrical shape (Festo, 2019)

6-Conclusion

Implementation of Spent nuclear rod storage in the simulation environment is a success. The process of simulation helps to showcase the knowledge on inverse kinematics, sensors, actuators, grippers, communication protocols between various systems and systems integration. Furthermore, the robot fails to reach a particular point at a desired joint value while multiple dynamic objects move at an instance and using inverse kinematics. Therefore, the simulation of multiple objects uses one step at a time approach rather than simulating multiple dynamic objects in a harmony. It appears that the CoppeliaSim simulation tool has a limitation over computing multiple dynamic objects at an instance.

7-Future work

7.1- Inverse kinematics approach

From the simulation, the robot navigates through the tight space in a curve path. As a future work, we simulate the robot navigating in a tight space with the inverse kinematics approach along with disengaging a particular joint. For instance, disengaging the joint in the red box as shown in the figure 29 and investigate whether the robot navigates through the hole in a straight path.

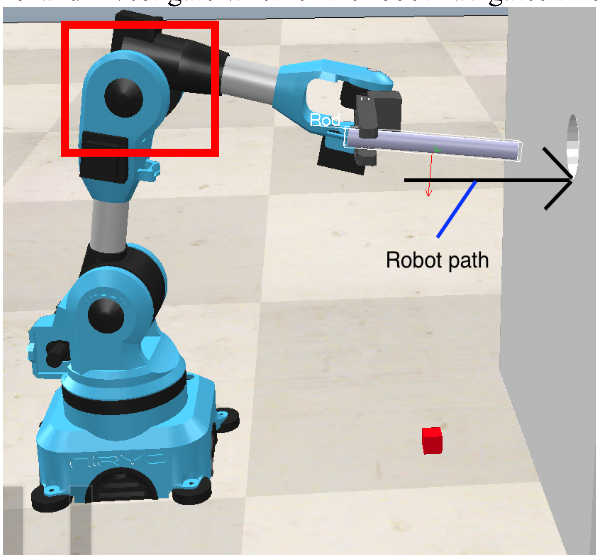

Figure 29- Niryo robot

7.2- Safety features

For the simplification process, we implement the simulation without safety feautures. However, the physical robot operations employ safety feature such as safety fencing using light curtain device as shown in the figure 30. Further simulation needs to validate the system safety.
In addition, the robot stops immediate with higher deceleration during the safety device engagement. Therefore, further work needs to investigate whether the robot holds the rod in the above situation.

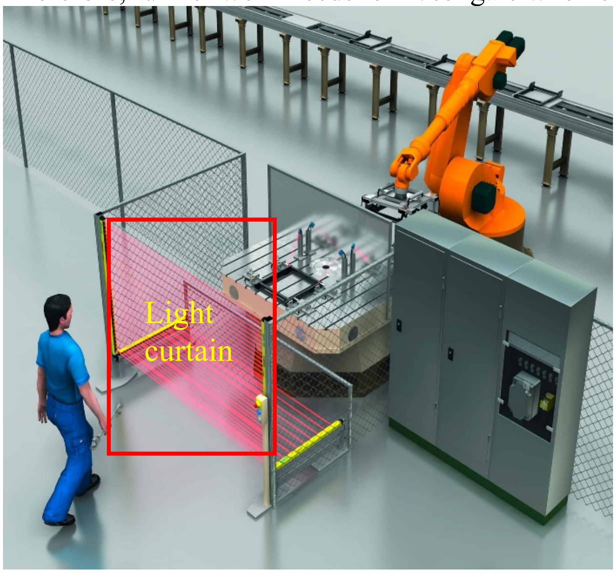

Figure 30- Representation of light curtains at a robot environment (Sick UK Ltd, 2017)

7.3-Electronic camming

As future research, the gantry system's joints can navigate using electronic camming to create a smooth and small motion profile (van Gerwen ,1999) as shown in the figure 31 compares with motion profile without electronic camming.

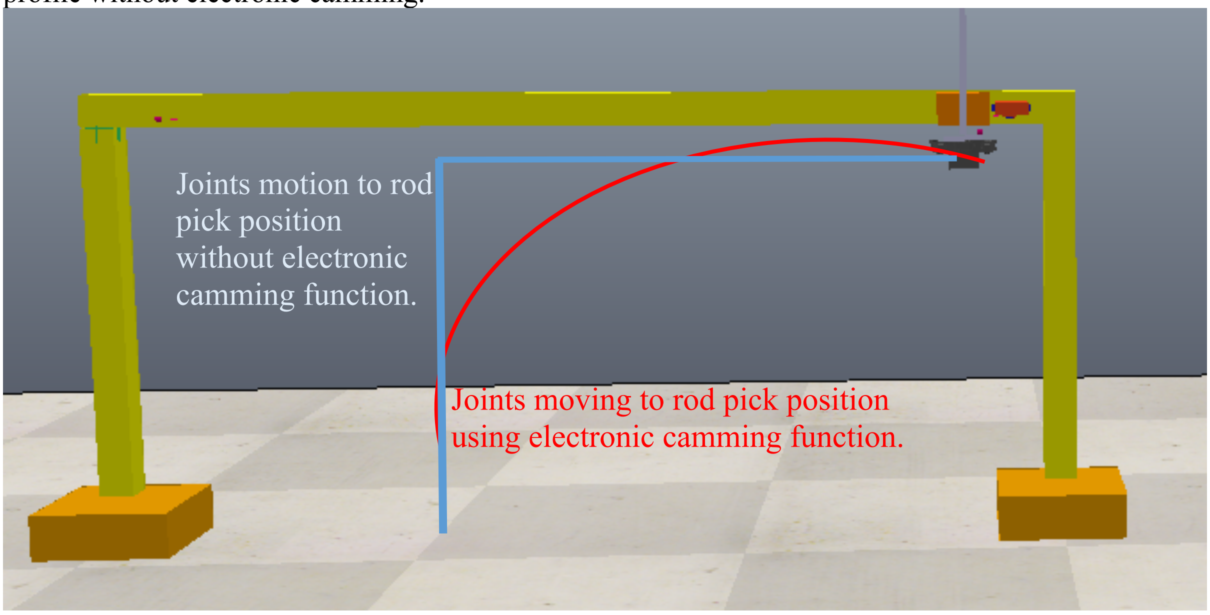

Figure 31 – Representation of gantry system motion profiles.

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