Robotic Replacement of Spent Nuclear Fuel Rods

The final project task is to simulate a robot tasked with replacing spent fuel rods in a nuclear reactor. Figure 1 shows a schematic layout of the playing field (the table). This resembles what you would see if looking down from above.

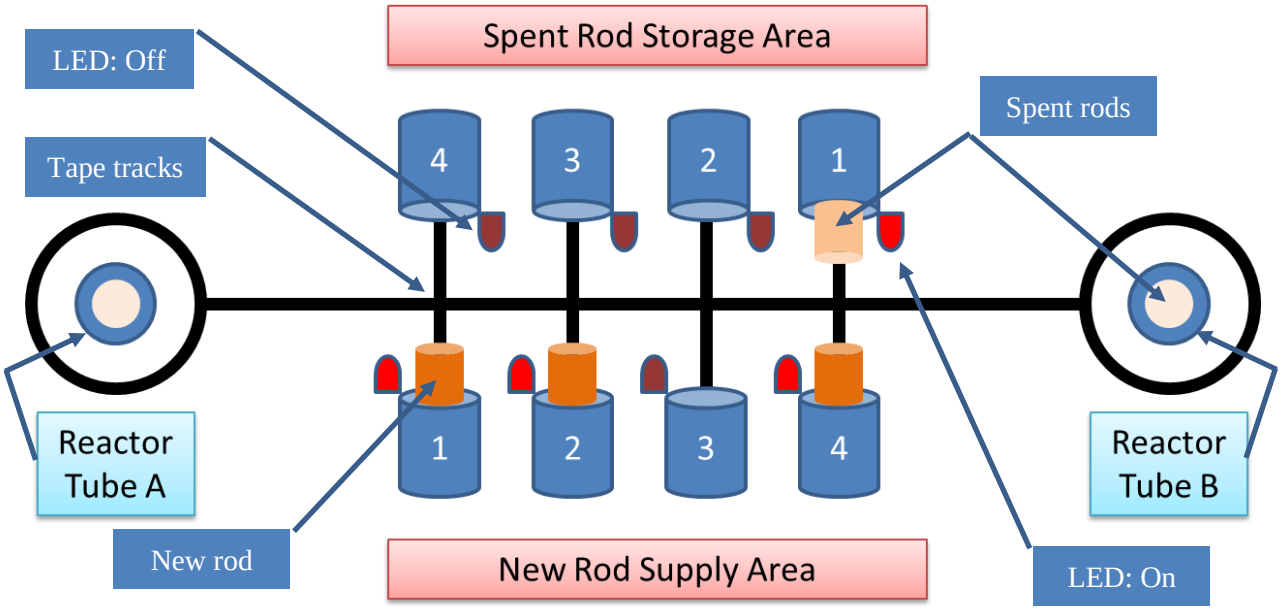


Figure 1: Playing field layout

There are two reactor tubes labeled A and B. Each has a fuel rod that is worn out, i.e. 'spent' and needs to be replaced. The reactor tubes, and the fuel rods contained therein, rise vertically from the table. The spent rod storage tubes and new rod supply tubes are positioned horizontally a short distance above the table in two rows between the reactor tubes. Each storage or supply tube has an associated LED; the LED is illuminated if a rod is present in the tube.

Briefly, the robot needs to:

- navigate to a reactor tube,
- remove the spent rod from the tube,
- find / navigate to an empty rod storage container,
- store the spent rod in the storage container,
- find / navigate to a supply container with a new rod in it,
- remove the new rod from the supply container,
- navigate back to the empty reactor tube,
- insert the new rod into the reactor tube, and then
- repeat the rod replacement process for the other reactor tube.

Additional details are provided below.

Task Details:

- The operator can drive (tele-operate) the robot up to a reactor tube. This will be a short (approximately 3 inch tall) vertical tube mounted to the table. This tele-operated driving is taking place via a high-bandwidth, real-time video connection from a camera onboard the robot.[1] A V-shaped notch on the front of the robot is allowed to gently push against the reactor tube in order to attain proper alignment with the tube.
- The fuel rod is a small diameter painted plastic rod that is approximately one inch longer than the reactor tube itself. The fuel rod will stay vertical within the reactor tube and is easy to extract and insert as long as it stays properly aligned with the tube. See Appendix A for details.
- The robot needs to autonomously remove the spent fuel rod from the reactor tube. The robot will need to use a vertical pull of several inches in order to have the rod successfully clear the tube. *Points will be deducted if the rod substantially rubs against the side of the reactor tube during rod removal or insertion* (such rubbing may damage the fuel rod and increases the cost to remanufacture it).[2]
- When the spent fuel rod has been exposed by removing it from the reactor tube, tele-operation is no longer possible. This is due to RF interference from radiation which reduces the communications channel bandwidth such that the notional remote video operation of the robot is no longer possible. Low bandwidth Bluetooth communications are still possible though – see below. The robot now needs to autonomously navigate its way to an empty fuel rod storage tube.
- The reactor control system (i.e., the playing field control computer) will communicate to the robot as to which storage or supply tubes are occupied. An occupied tube will have an illuminated red LED next to it. One way to proceed is that the robot could drive near to a tube and see whether or not it is occupied by using an on-board light detector. Alternatively (and worth additional credit), the robot can listen for 'tube availability' messages over the Bluetooth communications channel. The tube availability messages will need to be parsed to determine the state (occupied *vs.* unoccupied) of each tube.[3]
- The robot needs to lift the spent fuel rod to the correct height and align it with an empty horizontal rod storage tube; the rod is then inserted into the storage tube. There are several storage tubes (all at the same height) with tape marks leading to them from each vertical reactor tube. Once the spent rod has been placed in the storage tube, visual tele-operation may resume (but see below...). Physical alignment devices will be available on the playing field to aid the robot in getting properly lined up with the horizontal tubes. A funnel-like device is available on the storage tubes to aid in rod insertion.[4]

[1] The camera and video link is notional. We do not have sufficient resources for each team to have such a camera. Robot drivers will instead use their Mark I eyeballs to simulate the camera while tele-operating the robot.

[2] We will supply pre-made grippers to each team in the kit of parts. The team may design and use a different gripper if they wish.

[3] Just to make it more interesting, other message types will also be broadcast. Robots should additionally be aware that messages may be directed to other robots working in the area, so they need to pay attention only to messages addressed to themselves as well as those broadcast to all robots. See the message packet protocol for more details on robot addressing.

[4] In the interest of keeping things from being too difficult, points will not be deducted if a rod touches a horizontal tube during insertion or removal as long as it is reasonably well aligned with the tube.

- Having stored the spent rod, the robot may once again be tele-operated to pick up a new rod in the new rod supply area. Optionally (and for additional credit), the robot can autonomously navigate to an available new rod. As with the supply tubes, available new fuel rods can be determined by using LEDs next to the supply tubes, or by listening to the appropriate Bluetooth messages. As before, radiation will flood the area once the new rod is exposed. The robot must therefore autonomously navigate its way back to the empty reactor tube and insert the rod.
- While a fuel rod is exposed (either a spent rod being carried from a reactor tube to a storage tube, or a new rod being carried from a supply tube to a reactor tube), the robot must continuously display a visual alert (at least a flashing red LED). It should also broadcast 'radiation alert' messages over the Bluetooth communications channel for additional credit.
- If using Bluetooth in any way, a robot must respond as appropriate to all messages. These could be messages broadcast to all robots, or it could be a message sent to a specific robot. The 'address' for each robot is your assigned team number. See the message protocol for details. Failure to respond appropriately to Bluetooth messages will result in point deductions.
- A fourbar mechanism is required to be incorporated into the robot in some way. It should be used in a way that is meaningful and important to the operation of the robot.

Scoring:

There will be an overall time limit of 10 minutes for the game. The goal is to score as many points as you can during that time. Points are awarded or deducted as follows:

- 20 points will be awarded (each) for successfully pulling a rod from or inserting a rod into a reactor tube; 5 points will be deducted if the rod significantly rubs the side of the reactor tube during an extraction or insertion.
- 20 points will be awarded for properly inserting a spent fuel rod into a storage tube or extracting a new rod from a supply tube (no deductions for minor rubbing in these cases). If a rod is inserted into a storage tube but the LED does not light (i.e., the rod insertion was only partial), only 10 points are awarded.
- 20 points will be deducted for dropping a fuel rod (or if a rod falls out of a storage tube).
- 5 points will be awarded (per game) for using the LEDs to determine which storage / supply tubes are available.[5,6]
- 25 points will be awarded (per game) for decoding Bluetooth messages to determine storage / supply tube availability.[5,6]
- 20 points will be awarded (per game) for autonomously navigating from the spent fuel rod storage container to the new fuel rod supply container.
- 10 points will be awarded (per game) for appropriately responding to Bluetooth communications messages directed to all robots or to the particular robot on the course. Robots that respond incorrectly, i.e., they respond to messages directed to other robots, will not receive these points.
- 10 points will be awarded (per game) for properly broadcasting radiation alert messages over the Bluetooth communications channel.
- 5 points will be awarded (per game) for displaying the visual alert when carrying a fuel rod.

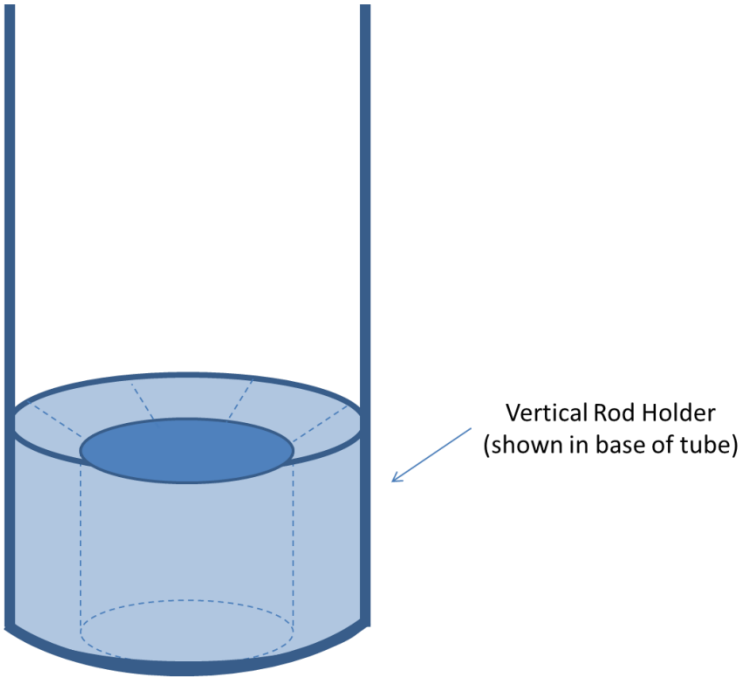
[5] Code will be reviewed to determine how this is being accomplished.
[6] Points will not be awarded for using ***both*** LEDs and Bluetooth. Only Bluetooth use counts in that case.

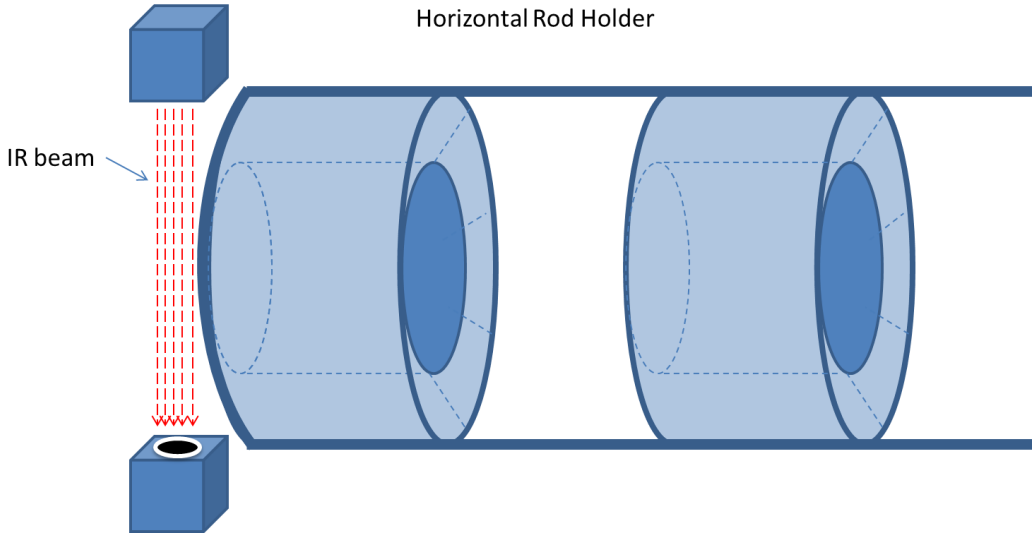
Project Goals:

- Require use of most of the material taught in RBE 2001 as well as material previously learned in RBE 1001.
- Demonstrate good software development and coding practices.
- Deal with a mix of autonomous and tele-operation in the robot tasks.
- Use Bluetooth communications for autonomous interaction with the reactor control system (e.g., the playing field control computer). A simple message-packet protocol has been defined to accomplish this. See the separate Bluetooth Protocol document for details.
- Demonstrate understanding of and an ability to use a simple message packet protocol (regular structure, addressing, checksums, etc.).
- [Optional] Use Bluetooth communications for debugging of untethered operation.
- Provide an opportunity for and encourage the use of:
  - a fourbar mechanism for a useful function
  - other mechanisms as appropriate

  to attain the different required orientations of the fuel rod (vertical and horizontal).
- Demonstrate, encourage and require good technical communications in the form of:
  - Supplied project documents
  - Informal preliminary design review
  - More formal critical design review
  - Final formal project presentation
  - Final formal project report
  - Demo of the robot in action

Appendix A


Vertical Rod Holder
(shown in base of tube)


Horizontal Rod Holder
IR beam