UNMESH MASHRUWALA
Innovation Cell
IIT BOMBAY

Freshmen Recruitment 25-26

Instructions for all the candidates:
(READ THEM CAREFULLY)

- The questions in Sections A and B **are compulsory for all to attempt.**
- There are four questions in Section C. You have to answer **only three out of the four questions.**
- Marks for section B will be awarded based on the uniqueness of your answer as well as the level of detail to which you write.
- Marks for section C will be awarded based on the amount of research you do on the topic and your level of understanding of the same.

Submission Guidelines:

- The answers are to be submitted in the form of a report no longer than 4 pages per question; the format for the same can be found here. Fill in your personal details properly.
- For submission, **make a copy of this document in your drive**
  - Fill in your personal details on page 2 along with the questions you will attempt
  - Delete all the other questions and write your solution just below the respective questions
  - Handwritten images are less preferable
- The deadline for submitting the answers is **9th Oct, 11:59 pm**.
- Use the following form for submitting your assignment in pdf form: https://forms.gle/rof6rGdZCyLNVHoHA
- Mention all the references used for answering the questions at the end of your answer.
- We do not expect you to have the prior technical knowledge required for answering the following questions, so feel free to use any online resources like online discussion, forums, journal papers, or even books.

UNMESH MASHRUWALA
Innovation Cell
IIT BOMBAY

To have a better overview of UMIC & the work we do, it is strongly suggested that you refer to the following resources:

Website: https://umiciitb.org/
Youtube: https://www.youtube.com/channel/UCkwi2H7zV2texcM6bQ_UagA
Facebook: https://www.facebook.com/innovationcell/
Instagram: https://instagram.com/umic_iitb?igshid=1vialpckb3scy
Linkedin https://www.linkedin.com/company/unmesh-mashruwala-innovation-cell-iit-bombay

And do join the the Whatsapp group for future and updates and to post your queries:

WhatsApp Group link | https://chat.whatsapp.com/J172lleSVyy2A5rBqYeA7T?mode=ems_wa_t

For any queries, feel free to contact:
Yash Gupta | +91 85869 32188
Yajan Agarwal | +91 75000 78990
Team Leaders, 2025-26
Unmesh Mashruwala Innovation Cell-IIT Bombay

Personal Information

Name:
Roll no:
Department:
Academic Program:

Mention which 3 Questions from Section C have you attempted	
Optional Question 1	
Optional Question 2	
Optional Question 3	

Section A:

This section is **compulsory to attempt.**

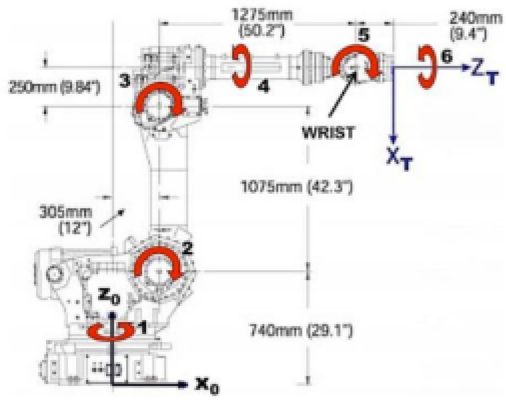
Q1 - General:
What are your short-term and long-term goals? (Answer in 150 words or less)

Q2 - General:
What is your motivation to join UMIC? (Answer in 150 words or less)

Section B:

This section is **compulsory to attempt.**

B1. 6-DOF Robotic Arm



The figure shows a 6-DOF industrial manipulator used in manufacturing. The provided image offers a basic foundation for a comprehensive study of the robot's capabilities and limitations.

<u>**Question Set**</u>:

1. Workspace Analysis

Given the total extent of the arm segments (L2≈305mm, L3≈250mm, L4≈1275mm, and L5≈240mm), what is the approximate **maximum horizontal reach** of the robot's wrist (Joint 5), assuming the base is fixed and all arm joints are fully extended?Also describe the **general shape** of the robot's total workspace

2. Singularity and Dexterity

- **Singularity Identification:** Identify **one major type of kinematic singularity** that this 6-DOF wrist-partitioned manipulator might encounter. Briefly explain the joint configuration (or condition) that causes this singularity.
- **Dexterity:** Explain why the **"WRIST"** section (Joints 4, 5, and 6) is crucial for the robot's dexterity and its ability to achieve **arbitrary orientation** of the end-effector.

3. Joint Velocity and Actuation

- **Axis Requirements:** Which of the three main arm axes (**Joint 1 (Base), Joint 2 (Shoulder), or Joint 3 (Elbow)**) would typically require the **highest torque** from its actuator? Why? (Hint: Consider the total mass it must move and the distance from the axis of rotation).
- **Speed vs. Precision:** In a pick-and-place operation, which joint (a primary arm joint, 1-3, or a wrist joint, 4-6) is typically designed for **higher angular speed**, and which is designed for **higher torque/load capacity**?

4. Application Suitability

- **Task Suitability:** Based on its configuration (articulated/anthropomorphic), suggest **two industrial tasks** (other than simple pick-and-place) for which this type of robot is particularly well-suited.
- **Load Capacity:** Given the overall dimensions and the likely payload, on the basis of the total reach calculated by you in the 1st part, what would be the expected highest typical payload capacity? Briefly explain your reasoning.

B2. Disaster-Relief Rover Challenge: Design a RescueBot

A disaster management authority has approached Sedrica to design an autonomous rover for post-earthquake rescue operations. The rover must navigate through semi-collapsed buildings, locate trapped survivors, and deliver emergency supplies. The terrain includes uneven rubble, narrow passages, partially blocked routes, and unstable debris. Survivors are identified using **wearable beacons** that transmit unique IDs, while supply packages are tagged with **QR codes**.

Your task is to design a rover that can operate reliably in this challenging environment.

Requirements:

1. **Rover Design**:
    - **Size & Mobility:** Define the rover's dimensions and locomotion mechanism (wheels, tracks, or hybrid) for moving on uneven terrain, climbing small obstacles, and squeezing through narrow gaps.
    - **Robotic Arm & Payload Handling:** Explain the design of the arm and gripper for picking up supply packages and carefully placing them near survivors.
    - **Beacon & QR Detection:** Describe how the rover will detect survivor beacons (with weak/noisy signals) and decode QR codes on supply packages in low-light,dusty conditions.

- **Stability & Safety:** How will the rover ensure balance while operating in unstable debris zones?

2. **Algorithm & Pseudo Code**:

   - Write basic pseudo-code for:
     - Locating the nearest survivor beacon and estimating their position.
     - Navigating through rubble to reach them.
     - Picking up the correct supply package and delivering it safely.

3. **Navigation & Mapping**:

   - Suggest the type of mapping and navigation algorithm the rover should use for partially known and dynamically changing environments.
   - Explain how it will reroute if debris blocks its original path.

4. **Error Handling & Obstacle Detection**:

   - Propose how the rover will handle errors such as false beacon signals, blocked passages, or dropped supply packages.
   - Describe how it will adapt in real time when encountering unstable terrain or after a failed attempt to deliver supplies.

5. **Additional Features**:

   - Propose one innovative feature that makes the rover more effective in real rescue missions (e.g., swarm coordination of multiple rovers, drone-rover collaboration for aerial mapping, or real-time survivor health monitoring).

Section C:

Attempt **any 3** out of the 4 questions from this section. Also **bonus points** if you attempt all the questions.

C1. Silent Infiltration Robot

UMIC Lab has a strict policy against leaving electrical appliances on when not in use. You, as a new recruit, were working diligently in the lab when you accidentally left the AC on and left for your hostel. Upon realization, you rush back to the lab to turn it off. However, to your surprise, you find Swadine, a senior engineer, sleeping near the switch. Disturbing him is not an option, owing to rumors of him being the kind of a person to hold a petty grudge. Thus, you need to turn off the AC silently.

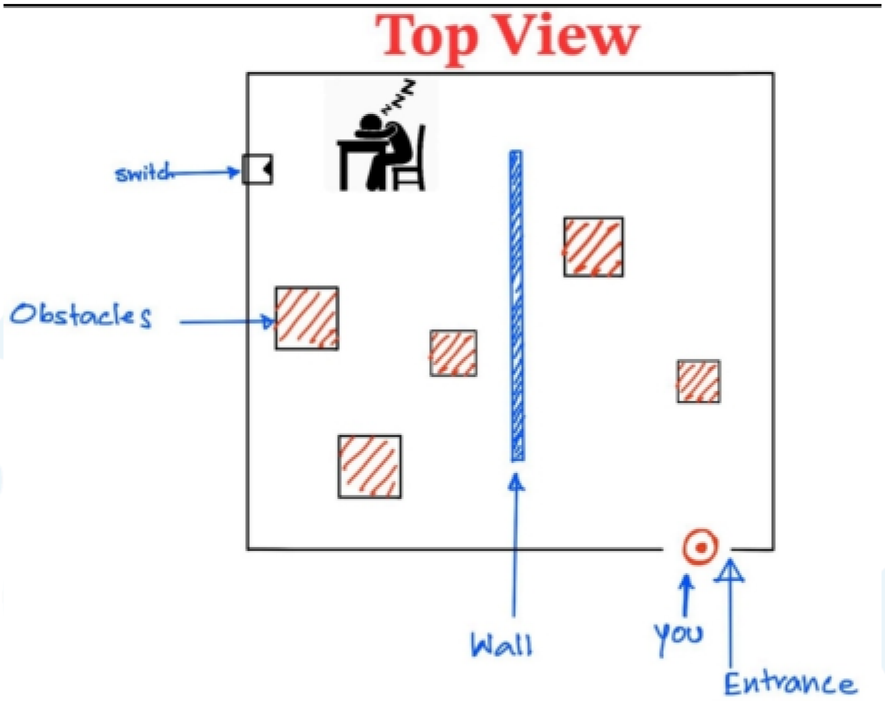
A) **Robot Design**:
- Create a detailed plan for a robotic system that can enter the room, navigate the obstacles,, and silently turn off the AC switch.
- You must consider the physical design of the robot, the choice of sensors, actuators, and the mechanical structure. A rough diagram is expected with list of electronic components required and reason for their choice

B) **Remote Access**:
- Develop a remote access system that allows you to operate the robot from a distance without making any noise. You can think on the lines of: cloud-based control, Wi-Fi communication, or even a gesture-controlled glove.
- Explain your choice and the components required.

C) **Programming**:
- Provide the basic Arduino code for the robot's movements, obstacle avoidance, and the stealthy AC switch turn-off operation.
- Describe the logic and algorithms used in your code.

Note:-

- Height of switch is about 4 feet from ground level
- You (your bot) does not know the exact location of obstacles on the floor


Top View
switch
Obstacles
Wall
you
Entrance

C2: Self-Driving Car Sensor Network Fault

You are an engineer developing a fleet of **15 autonomous self-driving cars** that must coordinate in real time to safely navigate a congested urban area. Each car has a **sensor synchronization module** that keeps all vehicles aligned to a common reference frequency for communication and decision-making.

However, intelligence suggests that an adversary may have tampered with one or more cars' modules, causing them to operate at a **slightly shifted frequency** (either higher or lower than the correct value). A mismatch will break coordination, leading to accidents and mission failure.

You can diagnose cars using a **pairwise comparison protocol**:

When two cars compare their sensor frequencies, one of three outcomes occurs:

- ✅ **Match** — both cars are synchronized at the same frequency.
- 📈 **Car A higher** — Car A's frequency is slightly higher than Car B's.
- 📉 **Car A lower** — Car A's frequency is slightly lower than Car B's.

Due to limited time and battery power, only a **small number of comparisons** can be made before the fleet must be deployed.

Constraints

- 15 self-driving cars labelled C1, C2, …, C15.
- **Case 1:** Exactly one faulty car exists (either higher or lower).
- **Case 2:** At most two faulty cars exist, and if there are two, then one is higher and one is lower.
- Each comparison is pairwise between two cars and yields one of the three outcomes above.

Goal

Identify the faulty car(s) and whether their frequency is higher or lower, using the **minimum number of comparisons**.

Objective

- **Part A — Single fault:**
  Design a strategy to identify the single faulty car and whether it is broadcasting higher or lower. State the minimum number of comparisons needed in the worst case, and justify why fewer cannot suffice.
- **Part B — Double fault (one high, one low):**
  Extend your strategy to identify both faulty cars (if they exist) and their relative frequency types (higher/lower). Again, aim for the fewest possible comparisons, and argue about optimality or near-optimality.

C3: The Asteroid Mining Operation (BONUS)

Background

Your company operates a mining station on a spherical asteroid with a radius of 5 kilometers. The asteroid completes one full rotation every 24 hours. To maintain operations and ensure safety, you need to establish an efficient **communication and transportation network** using **relay towers** and **tunnels**.

Operational Constraints

Relay Towers

- Must be built **only on the asteroid's surface**
- Each tower has a **line-of-sight communication range of 6 km**
- A tower can communicate directly with another tower if the straight-line distance between them (through space) is ≤ 6 km

Tunnels

- Can be constructed as **straight lines** connecting any two points on the surface
- Must pass through the asteroid at a depth of **at least 0.5 km below the surface** (for safety reasons)
- Walking speed through tunnels: **2 km/h**

- Walking speed on surface: **3 km/h**

The Six-Tower Optimization Problem

Your engineering team proposes to install exactly 6 relay towers on the asteroid's surface with the following conditions:

1. **Connectivity:**
   - Every tower must be able to directly communicate with at least 3 other towers
   - The network must be fully connected, meaning that any tower can reach any other tower, either directly or through a series of relays
2. **Distance Optimization:**
   - The towers should be positioned to maximize the minimum distance between any two towers
     (i.e., among all possible placements of 6 towers, choose the one where the shortest pairwise distance is as large as possible)

Your Tasks

1. Determine the optimal configuration of the 6 towers:
   - What geometric shape do they form on the surface of the sphere?
2. Compute the minimum distance between any two towers in this configuration.
3. Mathematically prove that this configuration gives the maximum possible minimum distance for 6 points on a sphere of radius 5 km.
4. Determine the number of direct communication links in the resulting network.

C4: Robot Painter Design Challenge

Background

The institute has identified that the **Energy Building** is long overdue for a visual upgrade. The plan is to install a **large, colorful mural** (e.g., a floral design) on the building's exterior wall. However, the administration is **not willing to invest in traditional methods**, which are expensive and would require shutting down the building for weeks.

As a result, **Team SeDriCa** has been tasked with designing and building an **autonomous or semi-autonomous robot** to complete this task more efficiently and cost-effectively.

Objective

Design a robotic system capable of **accurately painting a large-scale mural** on the vertical wall of the Energy Building, while satisfying a set of practical constraints.

Design Considerations

Your robot design should address the following key questions:

1. **Mobility & Positioning**
    - How will the robot move or reach different parts of the vertical wall accurately?
    - Will it climb the wall, use rails, cables, or be externally supported (e.g., via a boom/crane-like structure)?

2. **Paint Application Mechanism**
    - How will the robot **transport** and **apply paint** to the wall?
    - What mechanism (e.g., spray nozzle, inkjet-style applicator, roller) will be used to deposit paint precisely?

3. **Precision and Resolution**
    - Considering the mural will cover a large area, how **precise** does the paint delivery system need to be?
    - How will you **control resolution** and ensure visual quality across the mural?

4. **Use of Existing Building Features**
    - Can parts of the **building's structure** (such as windows, ledges, or beams) be used to your advantage?
    - Could these features help **reduce cost**, **improve stability**, or **simplify navigation**?

5. **Scalability & Structural Feasibility**
    - How well does your solution scale for very large murals?
    - Consider real-world structural issues (e.g., beams flexing over long spans). Will additional support structures (like thicker beams or tension cables) be required? How will this impact cost?

6. **Comparison with Traditional Methods**
    - Compare your robot-based approach with conventional painting methods (e.g., cranes and manual labor).
    - Consider ease of setup, repeatability, safety, and cost.
    - Make a rough **cost estimate** and comment on whether your solution would likely be **cheaper, safer, or more efficient** in the long run.

Your Task

Provide a **detailed description of your robot design**, including:

- The **overall mechanical structure**
- All **sensors** (e.g., for position tracking, wall distance, obstacle detection)
- All **actuators** (e.g., motors, paint sprayers, arms)
- Control systems and software components (e.g., path planning, feedback loops)
- Any **innovative mechanisms** or approaches you plan to use
- **Sketches or diagrams** to illustrate your design and layout

---

Deliverables

- Clear answers to each of the design considerations listed above
- Diagrams/sketches to support your design choices