Tab 1

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Instructions for all the candidates:

(READ THEM CAREFULLY)

- All the questions **are compulsory to attempt for section A .**
- There are 2 sections to the assignment.

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- You can attempt **any 3 questions in section B.**
- Marks for each section will be awarded based on the uniqueness of your answer as well as the level of detail with which you write.
- Marks for each section will be awarded based on the amount of research you do on the topic and your level of understanding of the same.

Query Sheet:

- In case you encounter any queries in any of the questions of this assignment, fill in your question in the following Google form.
- The answer to your question will be published here

IMPORTANT

1. Cite all your references, without fail!
2. Your aim should not be to finish the assignment. Just enjoy it, show your passion and efforts!

Submission Guidelines:

- The answers are to be submitted in the form of a report no longer than 3 pages per question. Fill in your personal details properly.
- For submission, **make a copy of this document in your drive**
- The deadline for submitting the answers is **9th October, 11:59 pm**.
- Use the following form for submitting your assignment in PDF form:

- 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

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

Website: https://aerove-ts.vercel.app/
Youtube: https://www.youtube.com/@innovationcell-umiciitbomb7768
Facebook: https://www.facebook.com/innovationcell
Instagram: https://www.instagram.com/umic_iitb/
LinkedIn: https://in.linkedin.com/company/unmesh-mashruwala-innovation-cell-iit-bombay

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Personal Information

Name:
Roll no:
Department:
Academic Program:
Year of Study:

Section A:

Q1 - General:

What are your short-term and long-term goals? (Answer in 150 words or fewer)

Q2 - General:

What is your motivation to join UMIC? (Answer in 150 words or fewer)

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Section B:

There are four questions in Section B. **You have to answer only three out of the four questions.** The question you attempt will not be representative of the subsystem you're selected for.

Q B.1

John, a third-year Mechanical student at IIT Bombay, is interning at a renewable energy company. He learns that the efficiency of wind turbines in the coastal regions of Maharashtra and Gujarat is significantly reduced by the accumulation of salt, dust, and grime on the turbine blades. Current cleaning methods involve manually rappelling down the blades, which is dangerous, time-consuming, and requires shutting down the turbine for extended periods.

John proposes a mechatronics-based solution: an autonomous drone designed to dock directly onto a turbine blade and perform localized cleaning. Your task is to develop the conceptual design for this system.

The drone must be able to fly to a specific, stationary turbine blade, securely attach itself, execute a cleaning routine on a targeted area, detach, and move to the next cleaning point on the same blade or a different one.

1. **System Architecture & Mechanical Design:**
    - Choose a suitable drone (e.g., quadcopter, hexacopter, octacopter)
    - The core challenge is to design two key mechatronic subsystems. For each subsystem, provide detailed diagrams (hand-drawn or digital CAD), describe the principle of operation, and justify your choice of actuators and materials.
        - **A) Docking and Adhesion Mechanism:** Design a mechanism that allows the drone to securely attach to the curved, composite surface of the turbine blade. Consider options like servo-actuated clamps, a pneumatic suction system, or an underactuated gripping mechanism. Your design should show the kinematics, actuator placement, and how it can withstand wind forces.
        - **B) Cleaning Mechanism:** Design a compact, lightweight robotic system to be carried by the drone. This could be a 2-DOF robotic arm with a rotating brush, a targeted high-pressure fluid jet system, or another novel solution. Your design must show how the cleaning tool is actuated and controlled. Also, detail how cleaning fluid would be stored and delivered.
2. **Sensor and Control System for Precision Docking:**
    - Describe the suite of sensors the drone would use to navigate the last few meters and perform the final docking maneuver with sub-centimeter accuracy. Explain the roles of sensors like LiDAR, stereo cameras, and force/contact sensors.
    - Outline the feedback control loop for the docking process. How would the drone use sensor data to adjust its position and orientation in real-time to achieve a secure attachment without damaging the blade?
3. **Actuator and Component Selection:**
    - Create a list of the primary mechatronic components specifically for your docking and cleaning mechanisms. For example: specific servo motors or stepper motors for the arm/clamps (provide torque/speed specs), pneumatic valves and pump for a suction system, a specific water pump for the cleaning jet, and force sensors for the docking mechanism. Justify why these components are suitable for the loads, power constraints, and precision required.

Q B.2

Consider the following five objects. For each one, answer the questions below.

1. A standard ceiling fan blade
2. A high-speed exhaust fan blade
3. The main wing of a commercial passenger aircraft (e.g., an Airbus A320)
4. The main rotor blade of a helicopter (e.g., a HAL Dhruv)
5. The propeller blade of a turboprop aircraft (e.g., an ATR 72)

Questions for each object:

a. Camber vs. Symmetry: Would you expect the aerofoil cross-section to be symmetric or cambered? Provide a clear justification for your choice.

b. Thickness: Would you expect the aerofoil to be relatively thick or relatively thin? Explain your reasoning.

c. Governing Factors: What are the top 2-3 factors that dictated your choices in (a) and (b)? Consider the following in your analysis:
* Operating Speed: Is it low speed (subsonic) or high speed (transonic)?
* Primary Function: Is the main goal to generate lift (perpendicular to the flow), thrust (axial force), or simply move air?
* Structural Requirements: Does the blade need to be very strong and stiff to handle high loads?

Now, focus only on the spinning objects (ceiling fan, helicopter rotor, and propeller). If you observe them closely, you'll notice their blades are not uniform from the center hub (the root) to the outer edge (the tip). The shape and orientation of the aerofoil change along the radius. This is called blade twist.

a. Why the Twist? Explain why the angle of attack (AoA) of the aerofoil section is deliberately varied along the length of the blade. *(Hint: Think about the tangential velocity, $v=\omega r$, where ω is the constant angular velocity and r is the distance from the center. How does this affect the relative wind seen by each section of the blade?)*

b. High Angle at the Root: Specifically, explain why the angle of attack is set to be highest near the root and gradually decreases towards the tip. What would happen if the entire blade had a single, uniform angle of attack?

Submission pattern:

- Structure your answers clearly by part and object.
- Use simple, annotated diagrams to support your explanations, especially for blade twist.
- Focus on the quality of your reasoning. The "why" is more important than just the answer itself.

Q B.3

Sam makes a remote-controlled quadcopter drone. As soon as he tries to fly it, a strong wind starts blowing, causing his drone to start drifting and making it very hard for him to control the drone. Thus, he approaches you to come up with a solution to this problem, so that he doesn't have to continually adjust his piloting to counter the wind.

1) (2 points) Suppose the drone has a mass m, and the wind exerts a constant force $\vec{F} = Fx\hat{\imath} + Fy\hat{\jmath} + Fz\hat{k}$ on the drone. Explain how you would make the drone continue to **hover** in the same location. Derive expressions for the **roll, pitch, and yaw** angles that would achieve stable hover in the wind. (Assume gravity = $-g\hat{k}$)

2) (4 points) You have now implemented your solution to part 1) in the drone, and it is hovering in the wind with its centre of mass at the coordinates (X, Y, Z) in the ground frame. Now the camera on the drone detects a bird at coordinates (xb, yb, zb) in the **drone's frame**. Derive the coordinates of the bird (Xb, Yb, Zb) in the **ground frame**. (Assume that Fx and Fy are small, so that roll and pitch angles are small)

3) (7 points) Now you want to make the drone semi-autonomous, so that it can respond to **changing wind** directions and magnitudes **automatically**. Suggest which **sensors** you would need to add to the drone to detect changes in wind. Consider the simpler case in which the variable wind acts only in the **z-direction**. Explain in detail the **control system** you would implement to make the drone capable of autonomously **hovering at a constant height**, battling the variable wind, using data from the sensors.

4) (7 points) Sam, impressed with your work, has now decided to give up on the remote controller altogether and has asked you to make the drone fully autonomous. The drone is now placed in a windless forest that has multiple **trees** that serve as **obstacles**. You are provided the **map** of the forest, i.e., you know the locations of the obstacles (trees). Given this map, suggest reliable algorithms for **planning an efficient path** for the drone from start to endpoint. Explain one of your approaches in detail. (Assume that the drone's altitude is fixed, i.e,. It only moves in the horizontal plane.

5) (Bonus question) When Sam was testing the autonomous drone, suddenly one of the 4 motors **failed** and stopped spinning immediately. What would happen in such a scenario? You, being the talented MPC engineer that you are, anticipate this motor failure. Explain in detail what mechanism you would add to handle the failure, to prevent the drone from crashing, and (if possible) to **continue stable flight**

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Q B.4

For the submission of question **B.4, PART 1 and 2**, the solution code files must be uploaded to a Google Drive folder, and the link must be provided in the submission PDF.

INTRODUCTION

You are a part of the perception team of a company specializing in aerial vehicles, called AeRoVe. Your CEO gets a call from the Defense Secretary of Utopia.

"We have made a world-class ornithopter, a flying vehicle that looks just like a real bird. It is just the size of a sparrow! We want to use it to confirm the locations of suspected terrorists by matching their faces, and capture images of crucial information like military equipment, bunkers, etc. Since these suspected sites are in the neighbouring land of Dystopia, with whom we do not have amicable relations, we need this to be covert. Our brilliant team has been able to pinpoint their location within a 100m radius. Beyond this point, due to jammers, the bird needs to be autonomous.
Here is what we want you to do. We will provide you with a rough 3D reconstruction of the person/arsenal, based on data from previous operations. We want you to design an algorithm to fly into the base, get a clear picture of the terrorist/arsenal from at least a few meters away. We don't have any other sensors on the bird except the camera, due to power and size constraints. Also, since you might need to go indoors, the bird needs to fly at roughly eye level. So, it cannot do any weird motions, rotating in place, going back and forth to analyze the location, etc. Its movements need to be very natural. Can you help us solve this perception problem?"

Of course, the CEO says yes. The bird (henceforth called drone) needs to make sense of the 3D world we live in, using 2D data from the cameras. You decide to start things off with a simpler problem. What if the drone lived in a hypothetical 2D world, where its cameras captured images in 1D? Any algorithm that works here should give an excellent starting point for the rest of the problem.

PART 1

Go through the provided code, especially its README. Play with the environment using test_env.py. The first task is to write a simple algorithm that can take the drone to the green checkpoint, as fast as possible, heuristically.

YOU DO NOT NEED TO TRAIN OR USE ANY AI ALGORITHMS FOR THIS PART. IT IS PURELY A CODING EXERCISE.
Rest assured, the required knowledge of Python is low enough to be learnt in a couple of days, from online resources. Any use of AI for coding this part will lead to serious penalties.

PART 2

The heuristics approach might work great in the 2D case, but it will simply fail in the 3D case (think about why? We might ask in the interview). So, you have now decided to implement an RL algorithm for the task.
Refer to videos explaining RL online. You do not need to know the maths, just an intuitive understanding will do. Then, read the documentation and basic usage examples of the Stable Baselines 3 library. You can use other Python libraries that implement RL algorithms, if you like. Then, train the policy and evaluate it to see if your drone is able to reach the checkpoint using RL. You do not need to modify any of the provided files. The final submission is all files related to your code, and a video of the GUI showing your algorithm controlling the drone, in at least 5 episodes.
You may use AI tools to understand the provided code and what RL is. You may also use AI to write evaluation scripts for your algorithm and debug code. However, you must write code to train the RL policy yourself, as we will ask questions about this.

Link to relevant code files - aerove_perception_assignment

THE FOLLOWING PARTS ARE RESEARCH QUESTIONS. NO CODE IS NEEDED. YOU WILL BE SCORED ON THE DEPTH OF RESEARCH YOU CONDUCT.

In the simplified 2D problem, the agent received a pre-encoded 1D signal indicating the relative position of the target. We now extend this setup to the 3D case.

Answer the following sub-questions. Each builds on the previous, so think about how your design decisions evolve as the environment becomes more complex.

PART 3

The world is empty except for the green target. How would you encode the input image before feeding it to the RL policy? Think of how you would ensure that your visual encoder can robustly handle perturbations like partial occlusion, fog, and unseen backgrounds. Justify your choice of architecture or feature representation.

PART 4

If we weren't in such a resource-constrained environment as the introduction provided, we could have used sensors and map the environment around the drone. This area is well-researched. How would you solve the problem in this case?

IMPORTANT

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4. Your aim should not be to finish the assignment. Just enjoy it, show your passion and efforts!