Freshmen Recruitment 24-25

Answer book

Instructions for all the candidates:
(READ THEM CAREFULLY)

- The questions in Sections A, B and C **are compulsory for all to attempt.**
- 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.
- There is a **bonus question** at the end, for some fun.

Query Sheet:
- In case you encounter any queries in any of the questions of this assignment, fill your question in the following google form: https://forms.gle/MKcAZVojVeWnSpmk9
- The answer to your question will be published in the following sheet
  Team UMIC AeRoVe Fresher Recruitment- Query form (Responses)

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
  - Explain your solution with diagrams and flowcharts wherever necessary
- The deadline for submitting the answers is **Thursday 10th October 11:59:59 (EoD).**
- Use the following form for submitting your assignment in pdf form: https://forms.gle/C5aSUDLvoqp5ZYVu6
- You are free to use the internet, however be thorough with your answers.
- *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 (use LLMs responsibly; they can be surprisingly deceptive in pulling incorrect answers out of nowhere; follow through with your own research, using LLM responses as nothing more than perhaps a starting point).

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

Team Website: https://aerovumic.vercel.app/
Instagram: https://www.instagram.com/umic_iitb/?hl=en
Linkedin: https://in.linkedin.com/company/unmesh-mashruwala-innovation-cell-iit-bombay

For any queries, feel free to contact:
Jainam Ravani | +91 93266 41433
MPC Subsystem Lead, Team AeRoVe

Tanmay Gejapati | +91 96326 72825
Perception Subsystem Lead, Team AeRoVe

Aayushi Barve | +91 73919 85746
Overall Coordinator, Team AeRoVe

Personal Information

Name: Guru Jahnavi Madana
Roll no: 24B1809
Department: Engineering Physics
Academic Program: Btech - fresher

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)

Ans: I joined IIT bombay this year itself (fresher), so am currently exploring stuff. My hobbies are painting and debating in culturals, so am currently into the activities conducted by those respective clubs. I am also developing my painting and debating skills. I am also so much into tech, especially the electrical part of it. Hence , I am also learning some electrical and code stuff that can be useful for the applications. I am learning Astronomy , as I always wanted to . In my free time I solve puzzles related to logic, Math and Physics. I do a lot of research about any topic that interests me, currently I am learning about fighter jets (previous topics include rockets and spaceships).

My short term goals - balancing academics with the activities conducted in the institute (tech and cultural) , CPI - (8 to 9). Developing my debating skills , and exploring more technical stuff. Complete reading book- hyperspace by Michio Kaku.

My long term goals- As of now I want to go into research and industrial applications (dynamic not static, can change in these 4 yrs) . Travel the world.

Q2 - General:

What is your motivation to join Team AeRoVe? (Answer in 150 words or less)

Ans:

Aerove looks cool.. I like the way drones and VTOLs work., so I would love to give my best for the team. I am passionate about the potential of drones to revolutionize industries such as agriculture, disaster response , and environmental monitoring. I'm driven by the challenge of pushing boundaries of what's possible with drone technology, and aerove's commitment to innovation and excellence aligns with my goals. I am also enthusiastic about learning new stuff.. I'm into the idea of crafting cutting-edge drones that aren't just gadgets but game-changers for industries like agriculture and emergency response etc.
Aerove isn't just about flying high, it's about soaring beyond the imaginable and I'm ready to add fire to this journey…

Yeah, it was fun solving the paper (especially Bonus , the physics questions and IARC problem)..., this also adds on to why I wanna join Aerove

Section B:

Q B.1:

You are working in a team that is developing autonomous drones for racing. The drones are designated A, B, C, and D, and their respective times to complete the race are 8 minutes, 9 minutes, 25 minutes, and 30 minutes. The drones must carry a baton (only one available) during the race to make it a valid submission.

For the competition, two drones have to go at the same time, with the slower drone carrying the faster drone. The traversal time will be equal to that of the slower drone. However, since only one baton is available after the two drones cross the finish line, one must return to the starting point to deliver the baton.

As a junior engineer, you have been asked to calculate the minimum time required for all four drones to be at the finish line at the end. To do this, you will need to consider the time required for each drone to complete the race, as well as the time required for the drones to return to the starting point to deliver the baton. Additionally, you will need to determine the optimal pairings of drones to minimize the overall racing time. Can you devise a strategy to accomplish this task?

Ans: Drone individual timings - A -8min, B -9min, C -25min, D -30min.
Lets analyze each pairwise timings - it will be the slowest drone's runtime.
AB - 9 min, AC - 25 min, AD - 30 min, BC - 25 min, BD - 30 min, CD - 30 min.

The race consists of the following pathway -
(Pair 1 trip)---->(return of a drone) —--->(Pair 2 trip)------>(return of a drone)----->(pair 3 trip)

The best strategy would be to include the fastest drone i.e, A in pair 1 and pair 2 so that the return time of drone will reduce by sending back drone A , minimizing overall time.

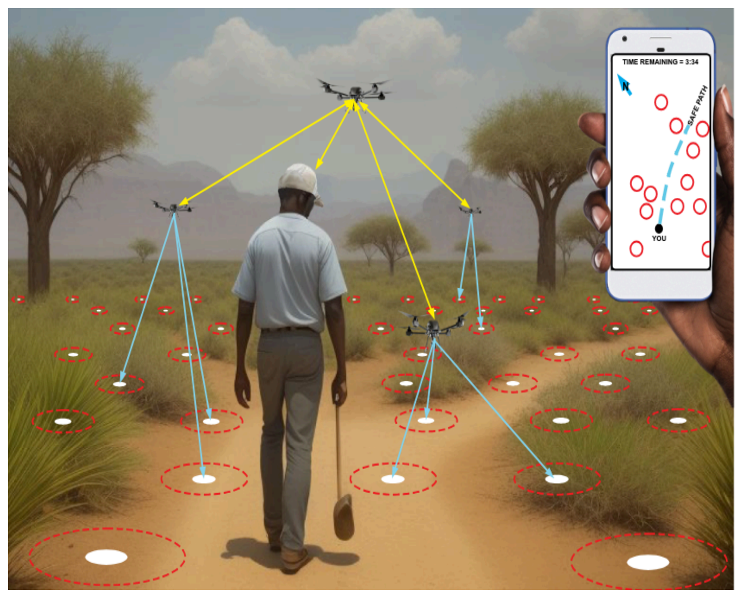
Therefore , the optimal pairings are - (AB) , (AC) & (AD). (any pair can be sent first, the ordering won't matter i.e, pair1 and pair2 can be any of the three pairs)

The runtime - (let us take the order of pair1- (AB) , pair2- (AC) & pair3 - (AD) for calculations)
(Pair 1 trip)---->(return of a drone) —--->(Pair 2 trip)------>(return of a drone)----->(pair 3 trip)
(AB)------------>(A) ———————————————>(AC)-------------->(A)----------------------->(AD)
(9min)--------->(8min) ———————————>(25min)---------->(8min)------------------->(30min)
The total time =
9+8+25+8+30= 80min (minimal time possible)

Section C:

If you attended the orientation, you are already familiar with our discussion on IARC Mission 10. Below, you will find the relevant details of the problem statement (the official problem statement), followed by a series of questions that represent the initial ideation phase our team undertakes before commencing a project. This exercise offers you a firsthand glimpse into our problem-solving approach and how we develop solutions to complex challenges.
While the mission's complexity has guided us to streamline the ideation process, please note that this is not the complete solution, but rather a part of it.

Background:



Anti-personnel landmines are explosive devices strategically placed beneath, on, or near the ground's surface. They are engineered to detonate upon the presence, proximity, or contact of a person, without discrimination between soldiers, civilians, or children.

During armed conflicts, soldiers are primary targets and often must traverse mine-contaminated areas. However, civilians engaged in daily activities such as farming, herding, and collecting resources like firewood and water are at significant risk both during and after conflicts. Economic necessities compel many in affected communities to enter hazardous zones. Children are particularly vulnerable, as they may inadvertently encounter mines while playing.

Currently, over 60 countries are contaminated with anti-personnel mines. The past decade has witnessed a troubling increase in casualties due to landmines and unexploded ordnance. In 2021 alone, at least 2,182 individuals were killed and 3,355 injured by these devices.

Mission Objective:

Develop and demonstrate a drone swarm capable of enabling a person to swiftly and safely cross a minefield by detecting mines and planning an avoidance path.

Given the above setup, you need to find an approach to solve the above task. Here we provide you a set of questions below (on the next page) which will help you achieve exactly the same but at a higher level of abstraction.

Swarm Advantages and Drone Selection

1. ***Enumerate at least four advantages of using a swarm of drones over a single drone for this mission.***

Ans: There are a lot of advantages of using a swarm of drones over a single drone . Some include-

1. **Increases the area coverage** - As the above mission is large-scale , a swarm of drones can divide the area and cover them simultaneously much faster than a single drone.
2. **Increases speed** - Multiple drones can gather data from different locations simultaneously, leading to faster mission completion.
3. **Increases accuracy and precision** - A swarm can provide multiple angles and viewpoints simultaneously, improving data accuracy and decision-making. Drones can gather data from different perspectives, allowing for better 3D mapping & mine detection.
4. **Increases Tolerance** - If a drone in the swarm fails or is disabled, the mission can continue with the remaining drones. This increases the resilience of the operation, unlike a single drone system where any failure could halt the mission entirely.
5. **Collaborative Problem Solving**- drones can coordinate their movements to manipulate objects, or carry out synchronized tasks that require precise coordination.
6. **Parallel Task Execution**- While some drones focus on gathering intelligence or data, others can engage in different tasks like obstacle avoidance, or communication relay, enhancing the overall mission efficiency.

Ref- [Swarm Drones: Features, Advantages, And Technological Framework - PWOnlyIAS](#)
[UAV swarm communication and control architectures: a review (cdnsciencepub.com)](#)

2. ***Among the following drone types—coaxial copter, hexacopter, quadcopter, and octocopter—which is most suitable for this mission? Provide a clear rationale for your choice. If an additional constraint limits the drone's weight to not exceed 1 kg, how would this affect your selection? Carefully evaluate your options and support your decision with relevant numerical data.***

Ans: Mission - Create and demonstrate a personal protection swarm to allow a person to rapidly cross a minefield without triggering a mine through avoidance.

The most suitable for this mission would be a **HEXACOPTER**.
Here's why -

1. Hexacopters strike a good balance between size, maneuverability, and stability. They can be agile enough to respond to dynamic situations, such as quickly avoiding obstacles while maintaining stable flight.
2. In a swarm configuration, the redundancy provided by six rotors means that even if one or two drones fail, the swarm can continue functioning without crashing. This increases the effectiveness of the mission.
3. It has enough lift capacity to carry useful sensors, such as cameras, infrared, LiDAR, or ultrasonic sensors, which are needed for mine detection and avoidance. The ability to carry sufficient payload, while maintaining good agility, makes it ideal for the mission.
4. They offer relatively good energy efficiency compared to octocopters. Their six rotors provide a good compromise between power and performance, ensuring the drones can fly long enough to complete the task without consuming too much power.
5. They have a reasonable flight time that is long enough to support the mission without overburdening the power systems, with their combination of lift and energy efficiency.

It provides a right balance of various factors, hence Hexacopter can be used for the mission.

If the constraint limits the drone's weight to **1 kg**, this significantly impacts the suitability of the different drone types for the mission.
The factors to consider are-

1. The capacity -the limit will restrict the size and weight of any equipment that can be mounted on the drone.
2. Heavier drones consume more power, reducing flight time.
3. Design characteristics that affect how it can operate within the 1 kg weight limit.

Numerical data-

DRONE TYPE	**TYPICAL WEIGHT**	**PAYLOAD CAPACITY**	**OVERALL WEIGHT**	**FLIGHT TIME**	**REMARKS**
QUADCOPTER	100-300 gms	200-400 gms	within 1 Kg limit	10-25 min	Less redundant
HEXACOPTER	500-1000 gms	100-300 gms	struggle to fit within the 1 kg limit	5-15 min	too heavy for this specific constraint
OCTOCOPTER	600-1000 gms	100-300 gms	too heavy for the 1 kg limit	5-15 min	big size and lack of agility
COAXIAL COPTER	200-600 gms	100-200 gms	fit within the 1 kg limit	15-25 min	More compact, less redundancy & stability,better maneuverability & flight

*payload weight- the equipment mounted on the drone
Considerations-

- Hexacopters and octocopters offer higher redundancy, which is important for safety in a minefield.
- Quadcopters and coaxial copters offer better agility, which is crucial for rapid and precise movements in a minefield.
- Both quadcopters and coaxial copters are more likely to accommodate sensors and payloads while maintaining the weight constraint.

Conclusion
Given the 1 kg weight limit, a **COAXIAL COPTER** would be a suitable option. As it provides adequate maneuverability and flight time . They also offer slightly better endurance and agility compared to quadcopters, though they may have fewer redundancies.

If redundancy and safety are of utmost priority , and if the mission can tolerate a small reduction in maneuverability a **LIGHTWEIGHT HEXACOPTER** could still be a viable option, but this would depend on careful optimization to stay within the weight limit.

Ref- Quadcopter vs Multirotor vs Hexacopter vs Octocopter | Grepow
Quad vs Hexa vs Octo -copter. (Radial and coaxial) Advantages-Disadvantages? - Discussions - diydrones
A Review on the State of the Art in Copter Drones and Flight Control Systems (mdpi.com)

Mine Detection Methods

1. ***Mine detection using aerial vehicles presents significant challenges. Propose methods by which mine detection can be achieved. This mission requires detecting four types of mines. Would your proposed method be suitable for each type?***

Ans: Deploy multiple drones in a coordinated manner to cover larger areas more efficiently. They can use different detection methods simultaneously, increasing the chances of locating mines. The different detection methods include-

1. Optical sensors
2. Radar sensors (use radio waves)
3. Acoustic sensors (use sound waves)
4. Magnetometers (detect subtle variations in the Earth's magnetic field caused by submerged metallic objects)
5. LIDAR
6. Synthetic Aperture Radar (SAR)- (use microwaves)
7. SONAR (underwater especially)
8. GPR(Ground penetrating radar)

A combination of approaches will give best results in mine detection.

The 4 types of mines - 1. Tripwire ,2. Tilt rod, 3. Pressure, and 4. Magnetic influence mines

MINE TYPE	DETECTION METHOD
TRIPWIRE MINE	Lidar, SAR & Multispectral Imaging
TILT ROD MINE	Optical, LIDAR & SAR
PRESSURE MINE	Pressure sensors,GPR, Data fusion (swarm drones), AUVs(underwater mines)
MAGNETIC INFLUENCE MINE	Magnetometers, AI analysis & Magnetic Anomaly Detection (MAD)

Employing a combination of these techniques will enhance the chances of successfully detecting all four mine types during the mission. (Tripwire, tilt rod and pressure mines can be detected by common means, but magnetic influence mines require a specialized magnetic detection)

Ref- Applications of Unmanned Aerial Vehicles in Mining from Exploration to Reclamation: A Review (mdpi.com)
(PDF) Landmine Detection with Drones (researchgate.net)
A Deep Learning Approach for Landmines Detection Based on Airborne Magnetometry Imaging and Edge Computing - ScienceDirect

2. ***Identify an appropriate sensor capable of capturing high-density data (e.g., similar to an RGB image) that can detect camouflaged or subterranean mines. Once selected, describe how you would process the data to detect different kinds of mines. Your detection pipeline should include:***
    - ***Data Acquisition***
    - ***Preprocessing***
    - ***Feature Extraction***
    - ***Classification***

Ans: Detecting camouflaged or subterranean mines is a challenging task, requiring specialized sensors that can penetrate the surface or detect subtle differences in materials, textures, or shapes.
An appropriate sensor capable of capturing high density data that can detect camouflaged or subterranean mines would be GPR and SAR.

DETECTION PIPELINE:

DATA ACQUISITION

Process:

- GPR uses radar pulses to image the subsurface. It sends electromagnetic waves into the ground and records the reflections from buried objects, voids, or changes in material properties. It is effective for detecting subterranean mines as it can penetrate soil, rocks etc.
- SAR is a form of radar used to create two- or three-dimensional images of landscapes. It sends radar signals from a moving platform and processes the returned signals to produce high-resolution images. It can be used to detect objects under foliage, sand, or water, making it useful for locating camouflaged mines.

Deploy the sensors over a wide area using drones, Record data overtime (waveform or 3D volumetric data)

PREPROCESSING

It ensures that the acquired raw data is clean, properly aligned, and ready for analysis.

For GPR data: use filtering techniques to remove clutter, Align the GPR signals so that the start of each signal corresponds to the same physical depth (Zero correction), Data normalization.

For SAR data: Align SAR data with geographic coordinates to ensure accurate location mapping, Apply filtering techniques, Calibration , Ensure alignment with other sensors such as GPR.

FEATURE EXTRACTION

It's useful to identify useful patterns or signatures in the data that can help differentiate between different types of mines and background material.

- For GPR

- Frequency domain - different subsurface materials can be identified with their respective frequencies.
- Look at the roughness or smoothness of radar signal patterns
- Different shape features can also be detected
- Time domain features -

  Signal amplitude- identifying strong reflections that could indicate dense, metallic objects

  Prolonged reflections indicate longer objects.

- For SAR
  - Mines or disturbed soil often have distinct radar backscatter characteristics caused due to differences in dielectric properties.
  - Ground texture can cause variations in the radar signal's intensity.

CLASSIFICATION

In here machine learning models or algorithms are used to classify regions or objects as mines and their types.

We can use the following methods to classify them:

1. Creating a dataset labeling sources as mines and non mines based on prior knowledge/history and then comparing the data obtained.
2. Using Machine learning models (Neural Networks)
3. Developing Anomaly detection algorithms.
4. Use context or neighborhood analysis to reduce false positives.
5. Combine the results from GPR and SAR to increase accuracy in the detection.

The above combination of GPR and SAR enables both surface and subsurface detection.

Ref- Detection Pipeline - an overview | ScienceDirect Topics
Mining Sensors and Detectors - Mining Technology (mining-technology.com)
Deep Learning-Based Real-Time Detection of Surface Landmines Using Optical Imaging (mdpi.com)

3. ***Explain how you would differentiate between decoy and active mines. Is this differentiation possible with your chosen sensor? If multiple sensors are required for classification, describe how you would integrate them.***

Ans: Differentiating decoy and active mines is very crucial as it can reduce resource waste and ensures an efficient mine clearing process. We can use advanced sensor technologies and data analysis methods to distinguish between decoy mines and active mines .

Active Mines: Usually have a more complex internal structure, particularly if they contain explosives and mechanical components (like detonators). These create distinct radar reflections.
Decoy Mines: Often simpler in structure, potentially hollow, or made of materials designed to mimic mines externally but lack the detailed internal complexity of active mines.

- We can differentiate by analyzing the reflection patterns and the material density, GPR can help identify irregular or hollow structures that might indicate a decoy mine.
- We can also use Metal detectors.
- We can also use Thermal imaging which can identify subtle heat differences, distinguishing decoy mines that lack thermal anomalies.
- We can use Chemical Vapour detection , which identifies the presence of explosives .
- Multi-sensor fusion and machine learning enable robust classification based on various features.

Yes, this differentiation is possible with my chosen sensors- GPR and SAR, when used together, they offer complementary insights into the nature of buried objects, including mines. Combining GPR and SAR allows for more precise identification by using SAR for wide-area detection and GPR for in-depth analysis of specific objects.

Integrating multiple sensors for mine detection and classification requires a structured approach to sensor fusion.

- The first step is to capture data from different sensors deployed on platforms like drones.
  Different sensors (GPR, SAR & Thermal imaging etc) produce different data types, such as radar echoes, spectral signatures, metallic conductivity ,or thermal maps. Each type of data contributes to understanding the nature of a buried object, whether it is an active or decoy mine.
- Preprocess them (filtering etc)
- Extract the Features (various methods)
- Classify them (Apply machine learning models)
- Real time processing / applications

Ref - Are there any sensors to differentiate between types of materials like plastic, paper and metal? - Quora
Improvements in GPR-SAR imaging focusing and detection capabilities of UAV-mounted GPR systems - ScienceDirect
/tardir/tiffs/a374029.tiff (dtic.mil)

4. ***Given the difficulty of obtaining real-world data to test your detection system, propose a solution to validate your approach using synthetic data that effectively adapts to real-world conditions***.

Ans: The solution is to replicate the real world conditions using synthetic data and ensure that the detection system works well. Synthetic data is information that is artificially generated rather than produced by real-world events.

It includes–

- Terrain modeling- Use terrain simulation tools to generate synthetic environments that resemble mine-prone areas
- Mine modeling- Include various configurations of how mines are buried (shallow, deep, tilted) or surface-laid.
- Introduce environmental variability such as different weather conditions
- Use small, well-curated datasets of real-world mine detection scenarios to benchmark the performance of the system
- Introduce time-based constraints, such as varying the speed of detection to test how the system performs under pressure or different search-and-clear scenarios.

By following these steps, synthetic data can be used to create a robust validation framework for mine detection systems.

Ref- Synthetic Data Generation: Definition, Types, Techniques, & Tools (turing.com)
Generating real-world-like labelled synthetic datasets for construction site applications - ScienceDirect

Obstacle Detection and Data Transformation

1. ***Which sensors would you employ for obstacle detection, considering they should remain relatively unaffected by various environmental conditions?***

Ans: Radar + LiDAR + Thermal Camera: This combination works best in detecting obstacles in most environmental conditions. Radar provides long-range detection in poor weather, LiDAR offers high-resolution 3D mapping in clearer conditions, and thermal cameras help detect living objects in darkness or fog.

2. ***Suppose one drone in the swarm has a superior mine-detecting sensor compared to the others. How would you incorporate this information into your algorithm?***

Ans: The superior mine-detecting drone can be seamlessly integrated into a swarm algorithm by assigning it specialized tasks, prioritizing its data in detection, and designing adaptive strategies that capitalize on its enhanced capabilities. It also enhances efficient coverage of the area.

We can use a dynamic task allocation algorithm to give priority to the specialized drone when the swarm identifies high-risk or complex areas where accurate detection is essential. This allows the swarm to deploy the superior sensor where it's needed most.

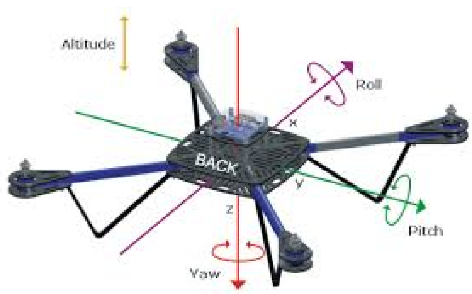
We can also incorporate a multi-layer detection strategy in the algorithm which includes scanning initially with general drones and then followed by focused scanning by the superior drone which helps in confirming or denying the presence of the mine with higher accuracy.

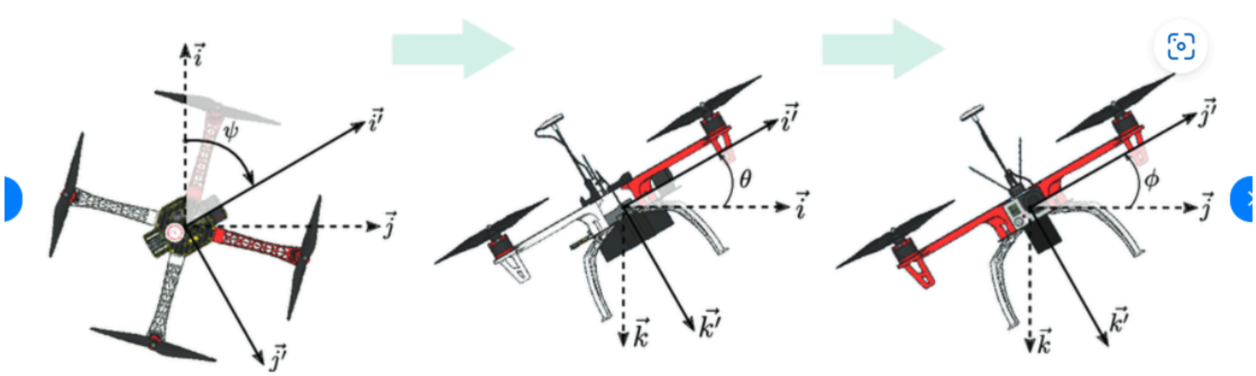
We can also establish a robust communication protocol that allows the superior drone to share detailed mine detection data with the rest of the swarm in real time based on which the swarm can change their behavior.

We can implement a centralized system that assigns tasks based on the drone's capabilities, giving priority to the superior drone for complex areas.

3. ***Review coordinate frame transformations to answer the following:***
    - ***At any time t, let the drone's center of mass be at position (x_{cm}, y_{cm}, z_{cm}) relative to a fixed origin, with a yaw angle ψ. Assume the drone is in a near-hover state with small roll (θ) and pitch (ϕ) angles.***
    - ***If you obtain the coordinates of a mine relative to the drone's center of mass as (x_m, y_m, z_m), derive the coordinates of the mine with respect to the fixed origin.***

Ans:

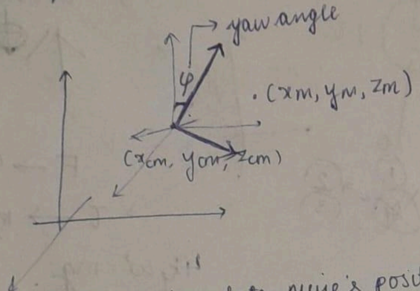




As roll and pitch are very small angles θ=0 and ϕ=0.

drone's centre ⇒ (x_{cm}, y_{cm}, z_{cm}) relative to a fixed origin.

mine's position ⇒ (x_m, y_m, z_m) relative to drone's centre



rotation due to yaw (φ)

rotation matrix :-

$$R_\varphi = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

to rotate mine's position by yaw angle φ :-

$$\begin{bmatrix} x_m' \\ y_m' \\ z_m' \end{bmatrix} = R_\varphi \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix}$$

$$\Rightarrow x_m' = \cos\varphi\, x_m - \sin\varphi\, y_m$$

$$y_m' = \sin\varphi\, x_m + \cos\varphi\, y_m$$

$$z_m' = z_m$$

Now, translation to shift from drone's centre of mass to the fixed origin;

$$x_M = x_m' + x_{cm} = x_m \cos\varphi - y_m \sin\varphi + x_{cm}$$

$$y_M = y_m' + y_{cm} = x_m \sin\varphi + y_m \cos\varphi + y_{cm}$$

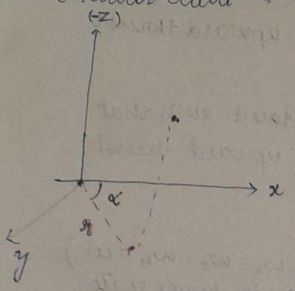
$$z_M = z_m' + z_{cm} = \cancel{z_m'} + z_{cm} \quad z_m + z_{cm}$$

4. ***One common sensor for survey missions is the 2D LiDAR. It provides data in a LaserScan format (α, r), where α is the angle relative to the drone frame's x-axis, and r is the distance to an obstacle at that angle. While effective for planar motion, aerial vehicles experience roll and pitch, causing the LiDAR scanning plane to differ from the ground plane. Given an array of such points, derive the method for transforming the data from the LiDAR frame to the world frame (relative to the fixed origin).***

Ans:

To world frame → roll (θ), pitch ($\emptyset$) & yaw (φ)

2D lidar data → laserscan format (α, r).



reference frame → drone's centre of mass

assume LADAR scans are in x-y plane

$$x_L = r\cos\alpha$$

$$y_L = r\sin\alpha \qquad [\text{w r t drone}]$$

$$z_L = 0$$

rotation due to roll (θ), pitch ($\emptyset$) & yaw (φ)

respective rotation matrices:

$$R_\theta = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \qquad R_\emptyset = \begin{bmatrix} \cos\emptyset & 0 & \sin\emptyset \\ 0 & 1 & 0 \\ -\sin\emptyset & 0 & \cos\emptyset \end{bmatrix}$$

$$R_\varphi = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

combined rotation matrix ⇒ $R = R_\theta R_\emptyset R_\varphi$

we get wrt to the drone's centre (x_{cm}, y_{cm}, z_{cm})

$$\begin{bmatrix} x_D \\ y_D \\ z_D \end{bmatrix} = R \begin{bmatrix} x_L \\ y_L \\ z_L \end{bmatrix}$$

wrt world frame; we need to translate from drone's centre

ie,

$$x_W = x_D + x_{cm}$$

$$y_W = y_D + y_{cm}$$

$$z_W = z_D + z_{cm}$$

5. ***Identify one major drawback of directly transforming data this way without additional constraints, assuming no measurement or processing noise exists. How would you address this issue?***

Ans: Directly transforming LIDAR data based on roll, pitch and yaw gives accurate results , but slight orientation errors can lead to distortions, especially near the ground. This can make it difficult to accurately distinguish ground features from obstacles.

To address this issue, we can add filters or sensor fusing with the IMU (Inertial Measurement Unit).IMUs offer faster and more accurate orientation information, using which we can calculate small deviations and align with an accurate world frame.

Ref- [What is sensor fusion? (sensortips.com)]
[Sensor Fusion Module Using IMU and GPS Sensors]

6. ***A false positive can occur when a drone mistakenly registers another drone in the swarm as an obstacle. Propose methods to mitigate this challenge.***

Ans: We can mitigate this challenge by inculcating -

- Better communication among the drones- Drones in the swarm can share their positions, velocities, and flight paths so that each drone can maintain a local map of the positions of nearby drones, and use this information to distinguish between obstacles and other drones.
- Using sensors- Combining sensors like radar, LiDAR, and cameras for classification of drones and other obstacles
- AI-Based Classification- Use machine learning models to recognize and classify drones
- Motion prediction

Ref - [Towards Resilient UAV Swarms —A Breakdown of Resiliency Requirements in UAV Swarms (mdpi.com)]

[Swarm Unmanned Aerial Vehicles (SUAVs): A Comprehensive Analysis of Localization, Recent Aspects, and Future Trends - Khelifi - 2022 - Journal of Sensors - Wiley Online Library]

Path Planning Algorithms

After collecting all necessary obstacle data and constructing a partial map of the minefield, suggest reliable algorithms for planning an optimal path for the soldier. Describe one of your approaches in detail.

Ans: One of the best algorithm is A* Algorithm in which we use grids to map the path. It can be used in places where the path must be safe, cost effective and short.

DETAILED APPROACH-

Grid representation, which includes representing the whole minefield as a 3D grid. Each cell in the grid corresponds to a small section of the minefield. We can classify the grids as ;

- free- no obstacle

- Occupied - has a mine
- Risk - closer to mines , but passable

The principal of A* algorithm -

- It is based on a cost function f(n), $f(n) = g(n) + h(n)$ which consists of an actual cost g(n) from the starting node to the node n and the estimated cost h(n) from the node n to the target node.
- h(n) is the heuristic function; it generally uses Manhattan distance, Euclidean distance or Diagonal distance to estimate the distance to the target node; g(n) is calculated as the real walking distance from the starting point to node n.

Application of the algorithm

- The grid cells representing mines are marked as obstacles and are assigned infinite or very high cost. Additionally, a risk map can be built, where cells near mines are assigned a higher cost to encourage the path planner to avoid them.
- Safe zones will have low cost g(n), while risky zones (close to mines) will have a higher g(n), disincentivizing the algorithm from choosing such paths unless necessary.
- The algorithm starts from the soldier's initial position and explores the neighboring grid cells. For each cell, it computes the cost function f(n)f(n)f(n).
- The cells are prioritized in a priority queue based on the cost f(n), with the lowest-cost cell being expanded next. Avoid paths that pass directly over mines (which have infinite cost).
- The algorithm continues expanding nodes, updating the cost for each node, and backtracking from the goal to the start once the goal is reached, forming the optimal path.

settings of heuristic function h(n) :

h(n) = actual cost	only find the best path, do not expand the node	Ensure to find the shortest path, and the path finding speed is very fast
h(n) ≤ actual cost	h(n) is smaller, A* expands more nodes	Ensure to find the shortest path and find the way faster
h(n) > actual cost	Find the best path and expand any other nodes	Can not guarantee to find the shortest path, and the path finding speed is faster
h(n) >> g(n)	A* algorithm evolved into a depth-first algorithm (DFS)	There is no guarantee that the shortest path will be found, and the path finding speed is very fast

Ref - IEEE Xplore Full-Text PDF:

Drone Motor Failure Recovery

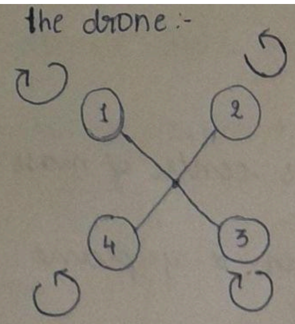
Just before mission completion, one of the drone's motors suddenly fails. Assume the following:

- ***The drone's mass is m.***
- ***It has a symmetric cross shape with motor-to-motor distance l.***
- ***The geometric center coincides with the center of mass (COM).***
- ***All four motors have force constants K_f and torque constants K_t.***
- ***The drone was in a perfect hover state before the failure, with all motors spinning at angular velocity ω.***
- ***Immediately after the failure, the faulty motor's speed drops to zero.***

Determine the new angular velocities that the remaining three motors must achieve to regain hover state.

Ans: **(next page)**

the drone :-



let,
the propellers for 4 & 2 be ~~placed~~ structured such that rotating anticlockwise gives upward thrust
where as,
the propellers for 1 & 3 be ~~placed~~ structured such that rotating clockwise gives upward thrust

before the failure;

Force balance :- $4k\omega^2 = mg$ (all ω's i.e, $\omega_1 = \omega_2 = \omega_3 = \omega_4 = \omega$) as the drone is in hover state

Torque is balanced as the drone is in hover state.

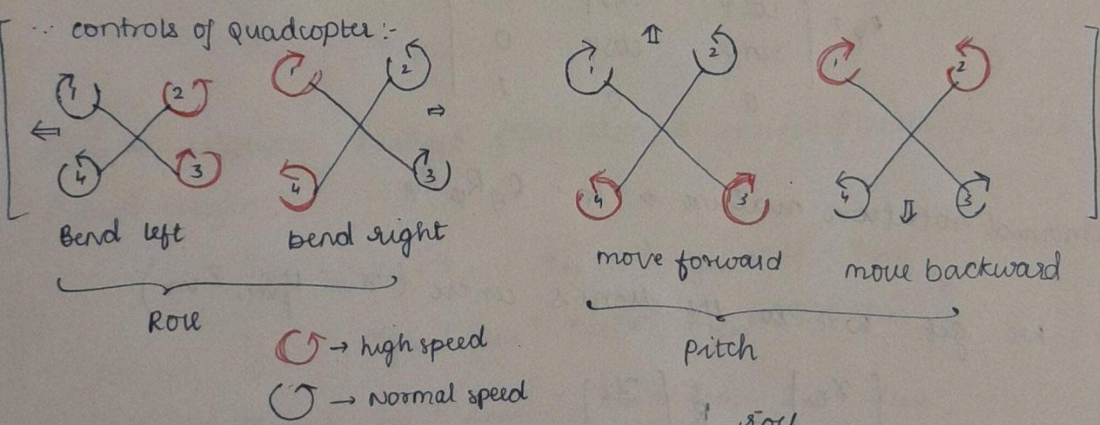
after the failure;

let the motor of 1 fail $\Rightarrow$ 1 stops $\rightarrow \omega_1 = 0$.

For the drone to hover; there should be no roll, no pitch & no yaw.

for no roll & no pitch to occur; $\omega_2 = \omega_4$

[$\because$ controls of quadcopter :-



]

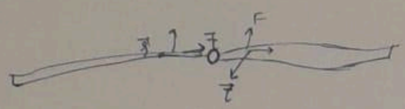
if $\omega_2 \neq \omega_4 \Rightarrow$ it will generate a bend/ ~~tilt~~ roll due to ~~No~~ unequal torque generated.

Force balance ;→ $k\omega_2^2 + k\omega_3^2 + k\omega_4^2 = mg$

$$2k\omega_2^2 + k\omega_3^2 = mg = 4k\omega^2 \quad [\because \omega_2 = \omega_4]$$

$$2\omega_2^2 + \omega_3^2 = 4\omega^2 \quad \text{--- (1)}$$

The when the propeller is rotated anti-clockwise & it generates an upward thrust;



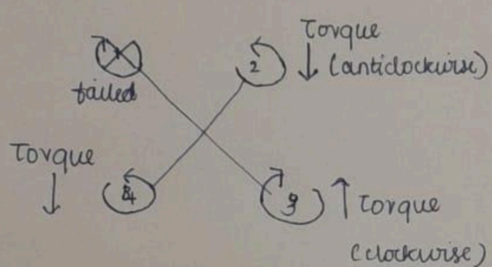
force acts $\perp$ upward

$\therefore$ $r \times F$ acts parallel to the plane of propeller & $\perp$ to $\vec{r}$.

$\therefore$ the net torque from both the wings results in the downward direction.

similarly clockwise rotation results in the upward direction.

$\therefore$ For our drone;



$\therefore$ torque balance;

$$\tau_2 + \tau_4 = \tau_3$$

NOTE: Force / Thrust force F is directly proportional to ω^2 due to aerodynamic principles. $\Rightarrow F \propto \omega^2$

[$\because$ propeller blades generate lift which is proportional to ω^2]

$\therefore$ both thrust & drag forces $\propto \omega^2$

- Torque produced by motor to maintain this angular velocity must counteract this drag, so the required ~~velocity must counteract this drag~~ torque must increase with ω^2

$$\Rightarrow \tau \propto \cancel{k}\omega^2 \quad \Rightarrow \tau = k_t \omega^2$$

$$\Rightarrow \tau_2 + \tau_4 = \tau_3 \quad \Rightarrow \quad k_t \omega_2^2 + k_t \omega_4^2 = k_t \omega_3^2 \quad \text{[torque balance]}$$

$$2\omega_2^2 = \omega_3^2 \quad \text{— ②} \quad [\because \omega_2 = \omega_4]$$

solving ① & ② $\Rightarrow$

$$\omega_2 = \omega_4 = \omega$$

$$\omega_3 = \sqrt{2}\,\omega$$

The drone'll regain its hover state, but wont stay horizontal, rather it'll be tilted up (slightly) at 3rd propeller as $\omega_3 > \omega_2$ & ω_4

Swarm Connectivity and Mission Continuity

Considering the importance of consistent connectivity in a drone swarm:

- ***How would you detect precisely when a drone becomes disconnected?***
- ***If a drone disconnects for an extended and unpredictable duration, how would you adjust to still successfully complete the mission? Consider aspects such as distributed sensor fusion and power management to meet the 10-minute mission requirement, along with other potential challenges.***

Ans:

- We can inculcate some methods which can detect the disconnections accurately and quickly. Which include-
    - Position Tracking
      Each drone broadcasts its position and status to neighboring drones or the base station. If position updates stop, the drone is assumed to be disconnected.
    - Mutual Monitoring
      In a swarm system, drones monitor each other's connectivity and status. If one drone stops communicating or falls out of formation, the others detect the absence of that drone.

Ref- A communication-based identification of critical drones in malicious drone swarm networks | Complex & Intelligent Systems (springer.com)

- In such a situation we need Dynamic adaptation of the swarm & effective use of the swarm.
    - If one drone disconnects, the other drones in the swarm must compensate for the loss of that drone's sensor data. In a swarm, multiple drones often overlap in their sensing regions. The remaining drones can share sensor data in real time to maintain an accurate and updated map of the environment.
    - Completing the mission within the 10-minute window while one drone is disconnected requires careful management of time and resources. The swarm should prioritize areas of the minefield that are critical to the mission and that require immediate attention
    - Power management becomes a critical concern when a drone disconnects, especially if the remaining drones are required to perform additional sensing or travel greater distances to cover for the missing drone. It should inculcate Adaptive power distribution in which the swarm can adjust the energy consumption of each drone based on current mission priorities.

Bonus Question:

As the main character of Interstellar, you find yourself in a hyper-dimension with lambda dimensions. You are amazed by the vastness and complexity of this new realm, and as you explore, you come across an object that seems to be unlike anything you've ever seen before.

Upon closer inspection, you realize that this object has **n** dimensions, a concept that is almost impossible for your three-dimensional mind to fully comprehend. You try to wrap your head around it, and after some thought, you realize that the object must be a cube in **n** dimensions.

As you continue to study the object, you begin to feel like you are just scratching the surface of its complexity. You start to wonder if there might be a way to better understand it, and then you remember something that you heard from an oracle in this hyper-dimension.

The oracle had mentioned a mathematical function, defined as

$$N := \left(\int_0^k \psi(\sigma)d\sigma\right)$$

Where,

$$10k = \sqrt{\sum_{t=1}^{\infty} \frac{6}{t^2}}$$

$$\psi(\theta) := \sqrt{\frac{23sin\theta - 63sin\theta cos^2\theta - 15sin\theta \sin^2 2\theta + sin3\theta cos^2\theta + 19sin3\theta}{8cos\theta cos4\theta + 8sin2\theta sin\theta - 4cos\theta}}$$

, that was specifically designed to study structures like this N-dimensional cube.

And you know that N is of the form of

$$N = a \times b$$

where $a \in \mathbb{Q}$.i.e. rational number in $\frac{m}{n}$ form with GCD of m and n being 1, and b being product of all other irrational terms.

Dimension of the object is 1/a and b is in the form of an irrational term, upon counting the number of edges you got to know it is of the following form

$$E = 2^u \times 5^p \times 7^q$$

Where p, q, and u are integers. Then find

$$\lim_{\zeta \to p+q} \zeta + \frac{19}{\zeta}$$

You have also figured out that in dimension(n) E ≤ 289

Ans: next pages

Numerator:-

$23\sin\theta - 63\sin\theta\cos^2\theta - 15\sin\theta\sin^2 2\theta + \sin 3\theta\cos^2\theta + 19\sin 3\theta$

$23\sin\theta - 63\sin\theta\cos^2\theta - 15\sin\theta\,\underbrace{(2\sin\theta\cos\theta)^2}_{4\sin^2\theta\cos^2\theta} + (3\sin\theta - 4\sin^3\theta)\cos^2\theta$
$+ 19(3\sin\theta - 4\sin^3\theta)$

$23\sin\theta - 63\sin\theta\cos^2\theta - 60\sin^3\theta\cos^2\theta + 3\sin\theta\cos^2\theta - 4\sin^3\theta\cos^2\theta$
$+ 57\sin\theta - 76\sin^3\theta$

$80\sin\theta - 60\sin\theta\cos^2\theta - 64\sin^3\theta\cos^2\theta - 76\sin^3\theta$

$\rightarrow 4(20\sin\theta - 15\sin\theta\cos^2\theta - 16\sin^3\theta\cos^2\theta - 19\sin^3\theta)$

denominator:

$8\cos\theta\cos 4\theta + 8\sin 2\theta\sin\theta - 4\cos\theta$

$= 4(2\cos\theta\cos 4\theta + 2\sin 2\theta\sin\theta - \cos\theta)$

$= 4\left[2\cos\theta(8\cos^4\theta - 8\cos^2\theta + 1) + 2(2\sin\theta\cos\theta)\sin\theta - \cos\theta\right]$

$= 4\left[16\cos^5\theta - 16\cos^3\theta + 2\cos\theta + 4\sin^2\theta\cos\theta - \cos\theta\right]$

$= 4\left[16\cos^5\theta - 16\cos^3\theta + 4\sin^2\theta\cos\theta + \cos\theta\right]$

fraction $\Rightarrow$

$$\frac{20\sin\theta - 15\sin\theta\cos^2\theta - 16\sin^3\theta\cos^2\theta - 19\sin^3\theta}{16\cos^5\theta - 16\cos^3\theta + 4\sin^2\theta\cos\theta + \cos\theta}$$

$-(16 + 4)\cos^3\theta$

$-20\cos^3\theta + 4\cos^3\theta + 4\sin^2\theta\cos\theta$

$4\cos\theta(1) + \cos\theta$

$\Rightarrow 16\cos^5\theta - 20\cos^3\theta + 5\cos\theta$ (denominator).

$$\sec^2\theta - \tan^2\theta = 1$$
$$\sec^2\theta = 1+\tan^2\theta$$

classmate Date Page

$$\frac{20\sin\theta - 15\sin\theta\cos^2\theta - 16\sin^3\theta\cos^2\theta - 19\sin^3\theta}{16\cos^5\theta - 20\cos^3\theta + 5\cos\theta}$$

divide N & D by $\cos^5\theta$:

$$\frac{20\tan\theta\sec^4\theta - 15\tan\theta\sec^2\theta - 16\tan^3\theta - 19\tan^3\theta\sec^2\theta}{16 - 20\sec^2\theta + 5\sec^4\theta}$$

N $\Rightarrow$ $20\tan\theta(1+\tan^2\theta)^2 - 15\tan\theta(1+\tan^2\theta) - 16\tan^3\theta - 19\tan^3\theta\cdot(1+\tan^2\theta)$

$20\tan\theta(1+\tan^4\theta + 2\tan^2\theta) - 15\tan\theta - 15\tan^3\theta - 16\tan^3\theta$
$-19\tan^3\theta - 19\tan^5\theta$

$\Rightarrow$ $20\tan^5\theta + 40\tan^3\theta + 20\tan\theta - 15\tan\theta - 15\tan^3\theta - 16\tan^3\theta$
$-19\tan^3\theta - 19\tan^5\theta$

$=$ $\tan^5\theta - 10\tan^3\theta + 5\tan\theta$

D $\Rightarrow$ $16 - 20(1+\tan^2\theta) + 5(1+\tan^2\theta)^2$

$16 - 20 - 20\tan^2\theta + 5(1+\tan^4\theta + 2\tan^2\theta)$

$16 - 20 - 20\tan^2\theta + 5 + 5\tan^4\theta + 10\tan^2\theta$

$1 - 10\tan^2\theta + 5\tan^4\theta$

fraction $\Rightarrow$ $\frac{N}{D} = \frac{\tan^5\theta - 10\tan^3\theta + 5\tan\theta}{1 - 10\tan^2\theta + 5\tan^4\theta}$

$= \tan 5\theta$.

$$N = \int_0^{k} \varphi(\sigma)\, d\sigma \qquad 10k = \sqrt{\sum_{t=1}^{\infty} \frac{6}{t^2}} = \pi$$

$$6 \times \sum_{1}^{\infty} \frac{1}{t^2} = \frac{\pi^2}{6} \times 6 = \pi^2.$$

$$N = \int_0^{\pi/10} \varphi(\sigma)\, d\sigma \qquad k = \frac{\pi}{10}$$

$$N = \int_0^{\pi/10} \sqrt{\tan 5\theta}\, d\theta \qquad \text{let } 5\theta = x.$$

$$5\, d\theta = dx.$$

$$N = \frac{1}{5}\int_0^{\pi/2} \sqrt{\tan x}\, dx \qquad \text{let} \quad N = \frac{1}{5}[I]_0^{\pi/2}$$

where $I = \int \sqrt{\tan x}\, dx$.

lets evaluate $\int \sqrt{\tan x}\, dx$

$$u = \sqrt{\tan x} \longrightarrow u^2 = \tan x$$

$$2u\, du = \sec^2 x\, dx$$

$$u^4 = \tan^2 x$$

$$\sec^2 x = 1 + \tan^2 x = 1 + u^4$$

$$\therefore \quad I = \int u \cdot \frac{2u}{\sec^2 x}\, du = \int \frac{2u^2}{u^4+1}\, du$$

$$= \int \frac{2}{u^2 + \frac{1}{u^2}}\, du$$

add & subtract $\frac{1}{u^2}$ in numerator

$$\Rightarrow \int \left[\frac{\left(1 - \frac{1}{u^2}\right) + \left(1 + \frac{1}{u^2}\right)}{u^2 + \frac{1}{u^2}} \right] du$$

$$\Rightarrow \int \frac{1 - 1/u^2}{u^2 + 1/u^2}\, du + \int \frac{1 + 1/u^2}{u^2 + 1/u^2}\, du$$

add & subtract 2 in denominator

$$\Rightarrow \int \frac{1-1/u^2}{\left(u+\frac{1}{u}\right)^2-2}\,du + \int \frac{1+1/u^2}{\left(u-\frac{1}{u}\right)^2+2}\,du$$

let $u+\frac{1}{u}=y$ & $u-\frac{1}{u}=z$

$dy=\left(1-\frac{1}{u^2}\right)du$ $\quad$ $dz=\left(1+\frac{1}{u^2}\right)dz$

$$\Rightarrow \int \frac{dy}{y^2-2} + \int \frac{dz}{z^2+2}$$

[Standard integrals:

1) $\int \frac{dx}{x^2-a^2} = \frac{1}{2a}\ln\left|\frac{x-a}{x+a}\right| + c$

2) $\int \frac{dx}{x^2+a^2} = \frac{1}{a}\tan^{-1}\frac{x}{a} + c$]

$\therefore$ The integral simplifies to;

$$I \Rightarrow \frac{1}{2\sqrt{2}}\ln\left|\frac{y-\sqrt{2}}{y+\sqrt{2}}\right| + c_1 + \frac{1}{\sqrt{2}}\tan^{-1}\frac{z}{\sqrt{2}} + c_2$$

$$N = \frac{[I]_0^{\pi/2}}{5} \Rightarrow$$

$$\frac{1}{5}\left[\frac{1}{2\sqrt{2}}\ln\left|\frac{\sqrt{\tan x}+\frac{1}{\sqrt{\tan x}}-\sqrt{2}}{\sqrt{\tan x}+\frac{1}{\sqrt{\tan x}}+\sqrt{2}}\right|+c_1+\frac{1}{\sqrt{2}}\tan^{-1}\left(\frac{\sqrt{\tan x}-\frac{1}{\sqrt{\tan x}}}{\sqrt{2}}\right)+c_2\right]_0^{\pi/2}$$

$$N = \frac{1}{5}\left[\frac{\pi}{2\sqrt{2}}-\left(\frac{-\pi}{2\sqrt{2}}\right)\right] = \frac{1}{5}\frac{\pi}{\sqrt{2}}$$

$$\therefore\ N = \frac{1}{5}\times\frac{\pi}{\sqrt{2}}$$

$$= \underbrace{a}_{\text{rational}} \times \underbrace{b}_{\text{irrational}} \longrightarrow a = \frac{1}{5} \quad b = \frac{\pi}{\sqrt{2}}$$

$\therefore$ dimensions of the object $= \frac{1}{a} = 5$

Number of edges in an n-cube :-

no. of vertices = 2^n (as each dimension contributes a factor of 2) :

each vertex in an n-cube is connected to n other vertices ($\because$ each vertex can be connected to each one in each dimension)

each edge connects 2 vertices

$$\therefore \text{ edges} = \frac{n \cdot 2^n}{2} = n\,2^{n-1}$$

here n = N = 5 dimensional

$$\therefore \text{ edges} = 5\;2^{5-1} = 5 \cdot 2^4$$

$$\therefore E = 2^4 \times 5^1 \times 7^0$$

$p = 1 \quad q = 0 \quad u = 4$

Now

$$\lim_{\zeta \to p+q} \zeta + \frac{19}{\zeta} = \lim_{\zeta \to 1} \zeta + \frac{19}{\zeta}$$

$$= 1 + \frac{19}{1} = \underline{\underline{20}}$$

THE END