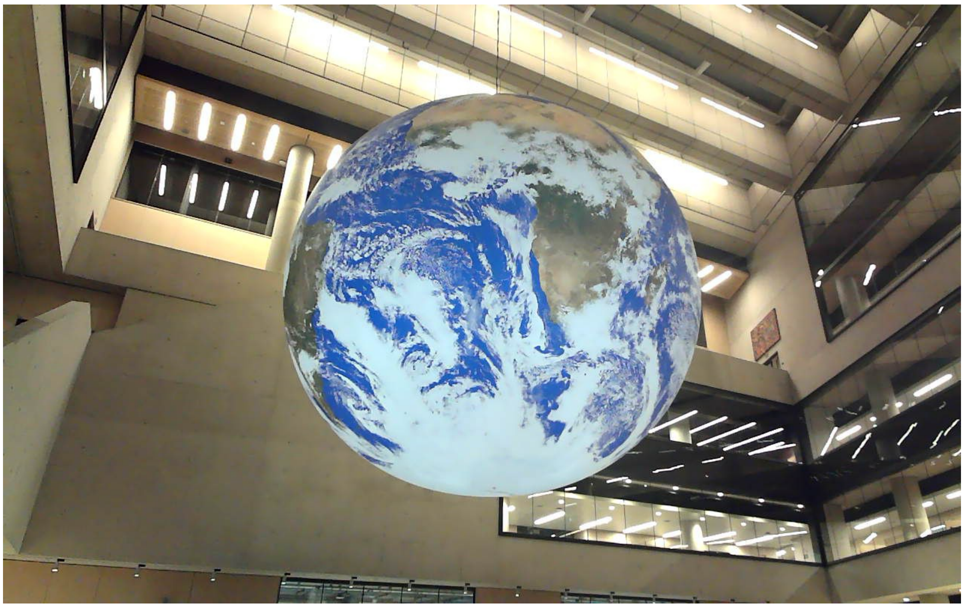
Final Grouped Project for COMP0241-2025

In this project, you will apply computer vision and sensing techniques to analyse a rotating model of Earth (referred to as the Astronomical Object or AO) suspended in Marshgate. Your objective is to perform measurements that will aid in planning a drone landing on the AO.



You are part of a space exploration team that analyses the AO, which rotates steadily around its vertical axis (yaw) but may exhibit slight swinging motions. Your mission is to perform various measurements using computer vision techniques to assist in planning a future drone landing.

High-Level Task Breakdown:

1. **Extract the AO Robustly from Images** (30%)
2. **Measure the Centre Point of the AO and Its Height** (25%)
3. **Estimate the Rotation Cycle of the AO** (35%)

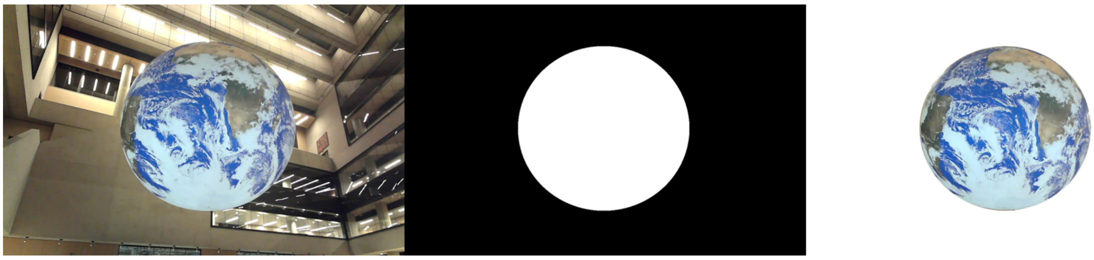
(You should finish tasks 1–3 before attempting task 4):

4. **Estimate the Landing Speed in the Earth's Coordinate Frame of the Drone** (10%)

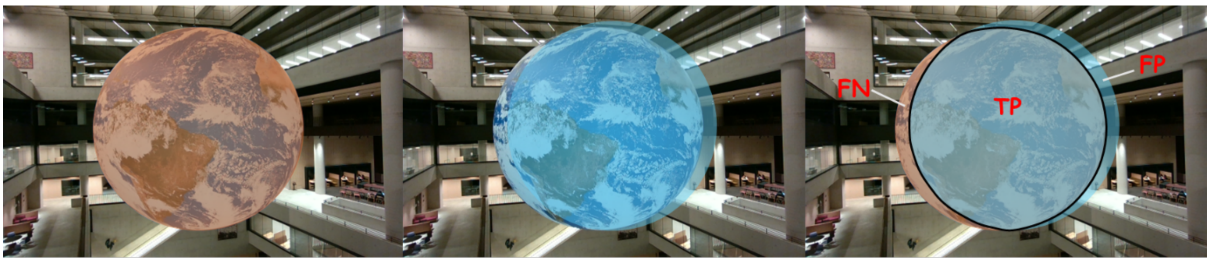
In General, for answering each question, you should demonstrate scenarios where your methods succeed and fail, explaining the causes.

Detailed Task Requirements and Mark Breakdown:

1. Extract the Astronomical Object from Images (30%)



1. Given an image of the AO, robustly extract it as a binary image mask.
   a. **Implement at Least Two Methods for AO Extraction (10%)**
      - Use different techniques (e.g., colour thresholding, geometry-based, such as edge/line extraction) to segment the AO from the background.
      - Demonstrate one example result of segmentation from `Easy/000016.png` in the test set and one image you captured, and qualitatively describe the result
   b. **Combine Methods for Improved Accuracy (5%)**
      - Integrate the methods in 1a to enhance extraction robustness.
      - Demonstrate one example result of segmentation from `Easy/000016.png` in the test set and one image you captured, and qualitatively describe the result
   c. **Evaluate Performance with ROC Curves (5%)**
      - Use the provided test set with ground-truth masks to plot ROC curves for each method from 1a on the same plot.
      - If a method has multiple parameters, fix all but one key parameter and vary that parameter to generate the ROC curve.
      - Explain your choice of the parameter you vary (e.g. why this parameter is most meaningful for controlling false positives / false negatives).



Ground Truth Mask Predicted Mask

Figure 1 Illustration of comparison between the predicted mask and ground truth mask.

d. **Pick the parameter for the combined method (10%)**

- Based on your parameter choices in 1c, perform a quantitative parameter search for the combined method from 1b.
- Produce either a 3D surface plot or a 2D heatmap, where:
    - The x and y axes form a grid over two parameters of the combined method.
    - The third dimension (height or colour) shows a chosen evaluation metric (e.g. Youden's J, or AUC, or other ones).
- Identify the best parameter pair using:
    - The extreme point on the surface/heatmap (e.g. maximum score), or
    - Another clearly defined criterion (e.g. gradient, elbow point).
- Explain:
    - Which evaluation metric did you choose and why?
    - How you used it to select the best parameter pair.
- Compare:
    - The "best" parameters found quantitatively here with the parameters you chose qualitatively in 1b.
    - Discuss differences in performance and the likely underlying reasons (e.g. lighting, texture, noise, parameter sensitivity).
- Use:
  - One image you captured, and
  - One image you selected from the test set to illustrate the differences.

2. **Measure the Projection Point of the Rotation Axis and the Height of the AO (25%)**

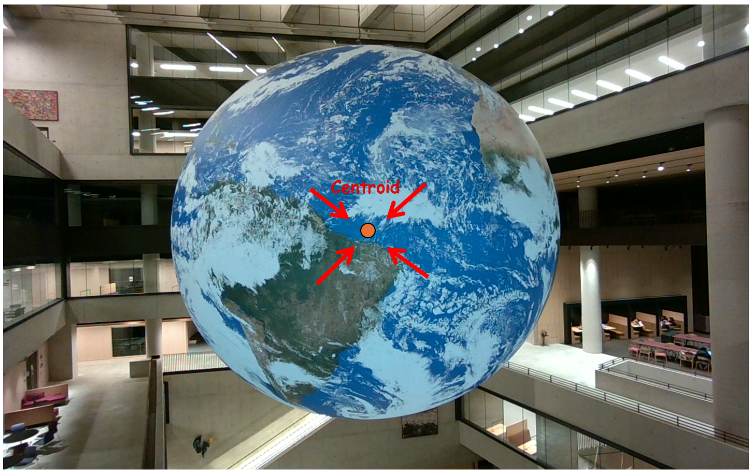


Figure 2 Example Centroid of the AO

   a. **Determine the Geometric Centre in Images (5%)**
      - Calculate the centroid of the AO using image processing techniques.

   b. **Assess the Movement of the Centre Over Time (10%)**
      - Analyse whether the AO's centre shifts due to swinging and quantify this movement with a static camera. Plot the trajectory over time.

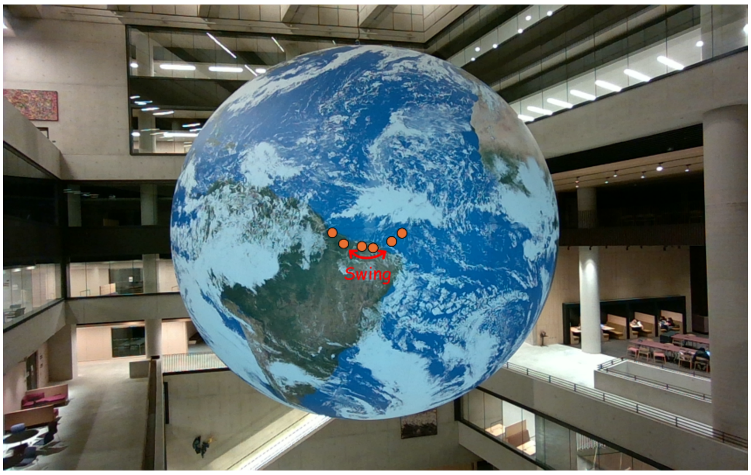


Figure 3 Example swing motion of the AO

   c. **Estimate the AO's Height Above Ground (10%)**
      - Use appropriate methods to estimate the vertical distance from the AO's lowest point to the ground plane. Justify the method you choose and validate your result with a secondary sensor measurement.

Figure 4 Example Illustration of the height of the AO

3. **Estimate the Rotation Cycle of the AO (35%)**
   Using your preferred method, estimate how long it takes for the AO to return to its original position.
   a. **Explain Your Methodology (5%)**
      - Clearly describe your approach for estimating the rotation period and justify its effectiveness.
   b. **Provide a Single Rotation Cycle Estimate (5%)**
      - Calculate the time for one full rotation of the AO (in seconds). You can just mark timestamping on the video with manual inspection. Do the cycle time vary?
   c. **Automatic Rotation Cycle Estimation from Video (5%)**
      - Automatically calculate the time for one full rotation of the AO (in seconds) and compare with the manual inspection result you have in 3.b.. (Your approach here does not need to be faster than the video play rate and you have the full video available at start)
   d. **Fast Rotation Cycle Estimation (5%)**
      - Implement your method to work faster than the video play rate and produce rotation cycle estimation (in seconds/rotation). You need to show that your method processes each frame faster than the frame rate. (Remember to disable visualisation for this.)
      - You can use a pre-recorded video (thus, on-the-fly estimation is not necessary, since you have later frames available too) and compare your processing time per frame with 1/framerate. Show something like this in the terminal for each frame: FPS: x / Processing time: y
        e.g. FPS: 30 / Processing time: 0.025s
   e. **Real-Time Angular velocity Estimation (10%)**
      - Improve your method to work in real-time, processing live video input. You need to show that your method could produce an angular velocity(in seconds/rotation) of the AO for each frame in real-time. (no future frames are available)
   f. **Compare Estimations from Different Views (5%)**
      - Perform estimations using cameras placed at two different perspectives (e.g., bottom view from ground looking up, side view) at the same time and compare the results of the rotation cycle over time. Show and discuss your approach for synchronising the video and the differences in results from different perspectives. You don’t have to limit to one method but meeting requirement of 3.e. is encouraged.

Table 1 Requirement of Task 3 sub tasks

<table>
<tr><th></th><th>Full Video at start or only see current frame</th><th>Process time for each frame (seconds)</th><th>Technique</th><th>Result per frame?</th></tr>
<tr><td>b</td><td>Full video</td><td>unlimited</td><td>Manual inspection</td><td>No</td></tr>
<tr><td>c</td><td>Full video</td><td>unlimited</td><td>Automatic</td><td>No</td></tr>
<tr><td>d</td><td>Full video</td><td>1/frame rate</td><td>Automatic</td><td>No</td></tr>
<tr><td>e</td><td>Current frame</td><td>1/frame rate</td><td>Automatic</td><td>yes</td></tr>
<tr><td>f</td><td>Optional, best approach above</td><td>Optional, best approach above</td><td>Automatic</td><td>Optional</td></tr>
<tr><td colspan="5">Can I do task 3e first and then use it for 3b,c,d?
Yes! Show that you solution satisfy those requirements in the earlier tasks</td></tr>
</table>

4. **Estimate the Landing Speed in the Earth's Coordinate Frame of the Drone (10%)**

Note: Before attempting this task, you should have made a good amount of attempts on tasks 1–3.

a. **Estimate the AO's Diameter and Evaluate Radius Consistency (5%)**

- Use measurements based on a 2D camera or other sensors and/or known references to calculate the AO's size.
- Determine if the AO's radius is uniform in all directions, and visualise your result.

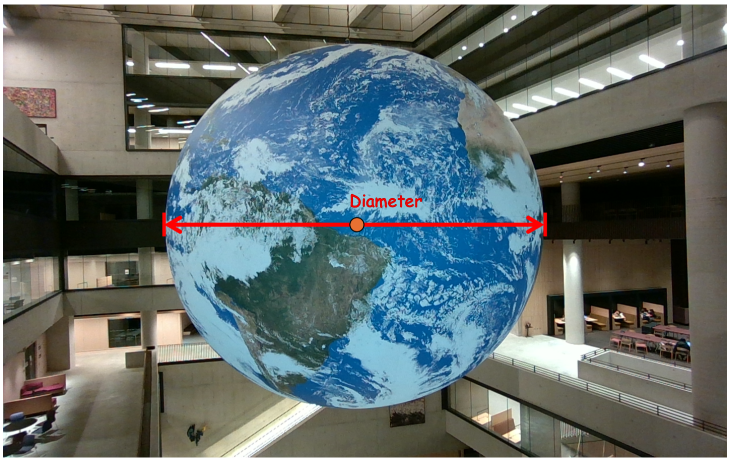


Figure 5 Illustration of the AO diameter

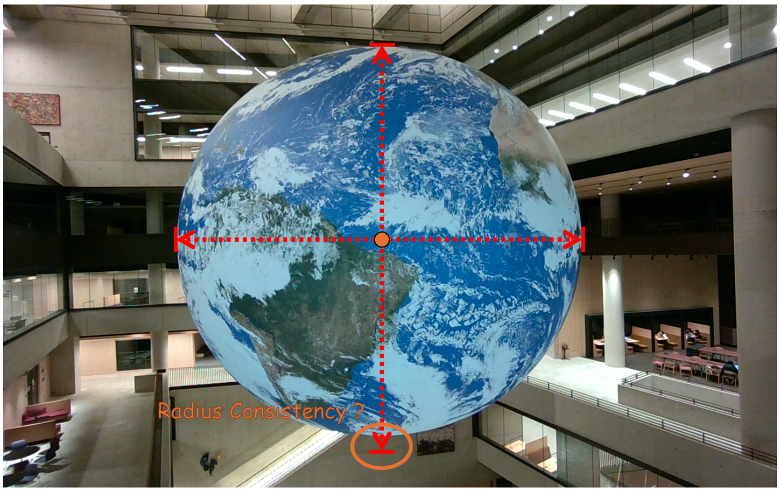


Figure 6 Illustration of the difference in diameter across the x and y directions.

b. **Calculate Surface Linear Velocity (5%)**

- Compute the linear velocity at various points on the AO's surface, expressing it as a function of latitude.

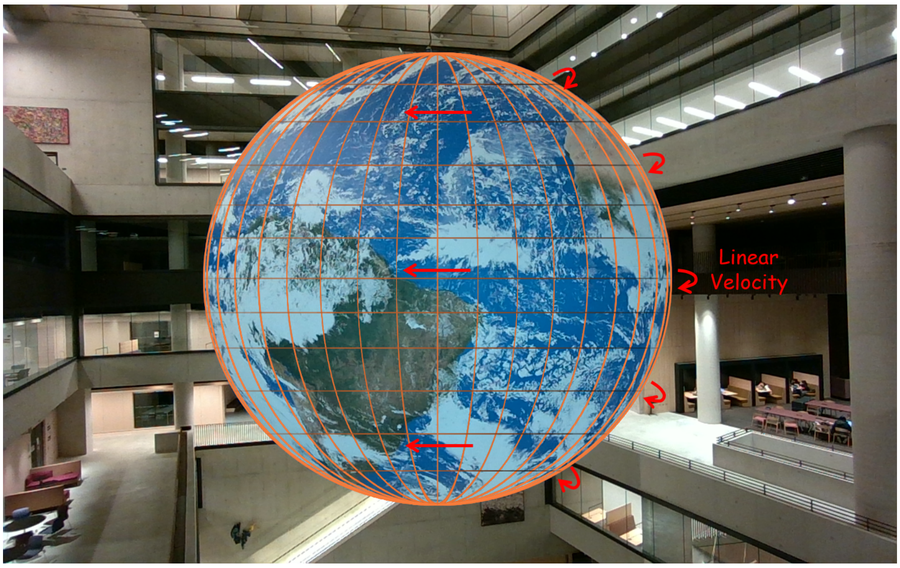


Figure 7 Illustration of the linear velocity with a latitude and longitude grid.

General Requirements:

1. **Sensor Usage:**
   - You should use the 2D camera(s) (Arducam global shutter RGB camera) provided as the main sensor. If one is not enough, share it among yourselves or ask us for another one.
   - We also have similar colours that are monochrome, consider them too.
2. **Use of Additional Sensors:**
   - You are welcome to borrow and use other sensors from us, as listed on the Week 0 slides, such as the Livox MID-360, MID-70 LiDARs, stereo cameras like the Intel D455, or the TOF camera Orbbec Femto Bolt, with the following constraints:
     a. **Data Capture Deadline:**
        - The last data capture must be completed before **17:00 on 11/12/2025**.
        - All data captured from other sensors needs to be uploaded to a shared directory within one hour of capture completion to be made available to all students.

     b. **Reporting on Additional Data:**
        - If you use these additional data in your project, you should state the following in your report:

          i. **Why do you need the new data?**
             - Is it necessary for your method for your task?
             - Does it improve the result or serve as ground truth for comparison?
             - If so, how much improvement does it provide?

          ii. **What is the new data?**
             - Describe the data content, format, location, and procedure for capture.
             - Mention any considerations you made during data collection.

          iii. **How did you use the new data?**

          iv. **Conclusion: Is it worth it?**

        - It's acceptable if you found the data just confirms your original result, as long as the initiative is justified.

3. Use of External Methods:
    - You can use methods outside the scope of the lecture and lab sessions.
    - If it is something you found from an external source, cite them appropriately (especially if it's from a Large Language Model).
4. Data Collection Tips:
    - To effectively record datasets, consider the following:
        - **Lighting Conditions:** Ensure consistent and adequate lighting to improve image quality.
        - **Camera Angles:** Choose appropriate angles to capture the AO effectively.
        - **Synchronisation:** If using multiple cameras, synchronise them properly to ensure accurate temporal correspondence.
5. Realtime:
    - It means that your methods should be able to finish processing the current frame before the next frame arrives. If the video is 30fps, your methods should be able to process each frame in 1/30 second (0.0333s). You could vary your input framerate, but please show evidence and statistics on the time needed to process each frame.
    - The initialisation time shouldn't be considered, but any pre-processing should be taken into account.
    - You could disable visualisation to speed the program up. But please provide evidence and comparison when you have the visualisation on.
    - Your Algorithm does not need to run in real-time unless explicitly asked in the individual task.
6. Choice of parameters:
    - If your method only performs well on either your own image or the test set with fixed parameters, it's your decision to pick the parameter for the final project. Justify your choices with segmentation examples on your own image if you want to prioritise your own image rather than the test case.
    - You don't have to maintain the same set of parameters for each task. e.g. segmentation parameter from task 2 does not need to be the same as task 1.

7. Sensor Calibration: Since you are expected to perform measurements, you should conduct calibration if necessary, with the methods shown in the innovation lab activities.

8. **Report Expectations:**

    - We expect you to write a rigorous report, in contrast to the notebook-style discussion you had for the lab sessions. We are looking for a thorough understanding and clear presentation. You should also aim to finish the basic tasks first before tackling harder ones. Plan your data collection by working out what data you need.
    - Page limit is 12 pages. Plan your space wisely.