Satellites Orbital Dynamics Lab

Introduction:

In this Lab, participants will utilise an Unistellar eVscope 2 to observe a few Starlink satellites. Participants are expected to calculate the orbital dynamics of the Starlink satellite using photos taken of the satellite along with an image of a reference object. In the process, participants are expected to calculate error propagation and add reasonable errors in measurements and justification for the errors added. (!) means possible change due to updates

Objectives:

- Operate a digital telescope
- Utilise image processing software
- Recognise and estimate errors in processing
- Calibrate instruments with existing knowledge
- Applying trigonometry in abstract spacial perspectives

Required Materials / Software

Mobile: Unistellar App

Computer: Gimp https://www.gimp.org/ &

SAOimageDS9 https://sites.google.com/cfa.harvard.edu/saoimageds9

Section	Marks
Section 1	/12
Section 2	/10
Section 3	/22
Total	/40

Section 1: Observation of satellite and reference object [10 + 2 bonus Marks]

In this section, participants are expected to familiarise themselves with how to operate the telescope in question, the telescope is an expensive piece of delicate equipment and should be handled with the utmost care. Please go through all steps and content before operating, there will be questions on operational knowledge that are graded for marks.

Note: there are activities that can only be done on certain dates, plan your observation early in case of inclement weather.

Procedures:

1. Go to https://www.youtube.com/watch?v=jiAstdnIHk8 to familiarise yourself with how to use the telescope and answer the following questions. Ensure you have downloaded the Unistellar App

    a. How do you verify that the tripod is level? Provide a reason as to why we should ensure that the tripod is level. [2 marks]
    b. How do you orientate the eVscope? [1 mark]
    c. Take a photograph of an image you / your team like and attach it to ensure that the object is visible by adjusting the exposure/gain/contrast etc. [2 marks]

2. Identify a night when there is a visible full moon. Using the Unistellar App catalog navigate to the moon and take a photo of a full moon. This will be your reference photo to calibrate your telescope. [2 marks]

3. Go to https://colab.research.google.com/drive/1P8pVLgyM2pNp4g_EShB6lESDMv52d92T and follow the instructions on the page to generate a list of Starlink satellites in a .txt file. (!)

    - UTM coordinates are 43.550842N, 79.664476W.
    - Note that the time input is in UTC please convert EDT to UTC by subtracting 4 hours from EDT
    - Generating targets will take some time, it is advised you limit your time range to a maximum of 2 hours

4. From the list of targets generated pick a minimum of 5 and a maximum of 10 targets that fulfil the following criteria. Copy and paste the selected target name, RA and DEC to your work [1 mark + 2 bonus](!)

    a. Each target is at least 6 minutes apart
    b. Declination is not +43˚±1˚ (explain why for a bonus mark)
    c. Declination is not >0˚ (explain why for a bonus mark)

5. Navigate to the direction of the path of the satellite 2 minutes beforehand by using the deep link provided. Begin the observation and wait until the 5-minute capture is done and repeat for all the targets you selected.

- !!! Make sure you visually confirm a capture by observing a fast bright streak on your app. You will need at least 2 confirmations if you did not manage to visually confirm a capture repeat from 3 for more targets until you get a minimum of 2 visual confirmations.

6. Park the telescope and upload the data you have captured and return the satellite.

7. Your TA will return the data you captured to you within a week. (!) You will be awarded 2 marks for successful data collection. [2 marks]

Section 2: Image Processing, Data Recording [10 Marks]

In this section, you will learn how to process images using Gimp and SAOimagesDS9. The raw data you have acquired are often hard to see as objects are either too bright/dim. As such these apps make lives easier by changing colors/contrasts to make objects more visible and also come with the tools to record data.

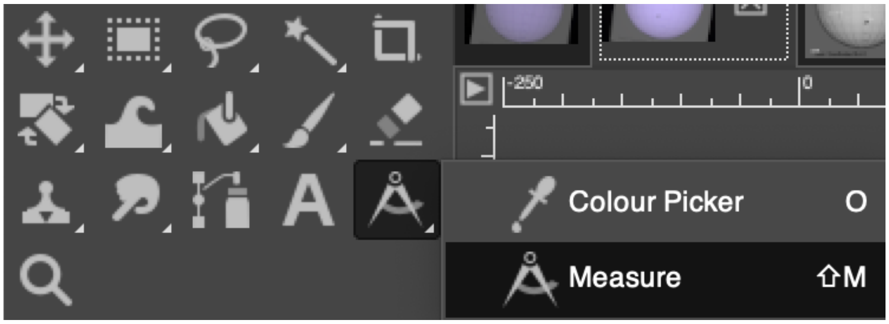
Procedures:

Part 1: Satellite Streaks Processing

1. Open SAOimagesDS9 and the collection of images for 1 satellite on the app.
2. Under “Frame” click on “Blink” to automatically switch frames. If you do not see anything try adjusting the contrast via “Scale” Feel free to try out different modes best suited for the purpose of identifying a streak.
3. Identify the frames which have a streak not intersected by the edge in them and remove the rest, pick out 1 image with a streak and attach it to your work [1 mark]
4. By moving your cursor to the start and the end of the streak, how long is the streak on average in pixels? [1 mark]
5. Repeat steps 1-3 for another satellite [1 mark]
6. Are there any errors associated with your measurement? Give an estimate and justify your estimate [2 marks]
7. For all of the selected frames, under “Files” check the header and state the exposure time and elevation of the telescope. [1 mark]

Part 2: Reference photo processing

1. Open GIMP and your choice of a frame of the moon
2. On the top left toolbar, by right-clicking on the icon seen below select a measure or press shift+M



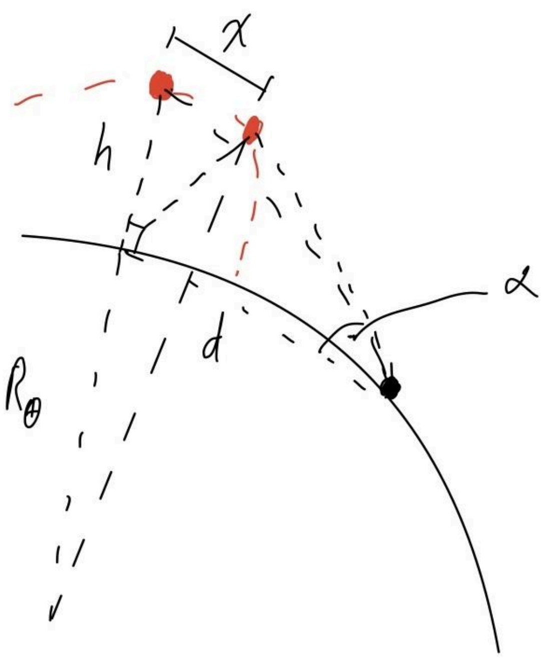
3. Select the measure tool and press on one edge of the moon, set the other on the other side, by adjusting one side of the marker find the maximum length of the moon in pixels [2 marks]
4. Record the length of the moon in pixels, Are there any errors associated with your measurement? Give an estimate and justify your estimate [2 marks]

Section 3: Calculations [20 marks]

In this section, using the data you collected and some commonly found data, you will find the field of view of the telescope and the orbital dynamics of the 2 satellites. You will be required to calculate the error propagation as well, such equations can be found in the appendix. Please state all the assumptions you have made and provide a reason.

Questions:

1. Look up the radius of the moon, distance to the moon and calculate the angular size of the moon [2 marks]
2. Using the pixel size of the moon and the angular size of the moon from 1. find the field of view of each individual pixel [1 mark]
3. Using the following image to help wrap your head around trigonometry, answer the following questions for images of both satellites taking the average among the frames.



   a. Using the angle of elevation (α) you acquired and provided that the height of orbit of Starlinks satellite is around 550KM find the shortest distance between you and the point where the satellite will pass at the zenith (d) [2 marks]
   b. What is the straight line distance (x) travelled by the satellite [2 marks]
   c. Find the arc travelled by the satellite with respect to the centre of the earth [2 marks]
   d. Find the period of the satellite using the exposure time of each frame and your answer from part c [2 marks]

    e. Given that each satellite has a mass of 260 kg find the velocity and total energy of the 2 satellites [4 marks]

4. Suppose that we jumped to question 3c and used the the length of streak directly will we expect a greater or lesser period? Explain your answer [2 marks]
5. How significant are your errors for answers in 3d and 3e? If you can eliminate 1 error from your measurements, which one would reduce your error the most? Suggest one way to reduce this error [3 marks]
6. Bonus: suppose that you are in a rocket chasing the satellite at the same velocity, which direction should you fire your rocket to catch up to the rocket? Explain your answer. [2 marks]

Appendix: Propagation of Error:

For a variable z derived from independent measurements, $x_1, x_2, \cdots, x_n$ the general rule for error s_z is:

$$s_z = \pm\sqrt{\left(\frac{\delta f}{\delta x_1}\right)^2 s_{x_1}^2 + \left(\frac{\delta f}{\delta x_2}\right)^2 s_{x_2}^2 + \cdots + \left(\frac{\delta f}{\delta x_n}\right)^2 s_{x_n}^2}$$

For special cases such as:

1. Sum/difference $z = x + y$

$$s_z = \sqrt{s_x^2 + s_y^2}$$

2. Product and quotient $z = x \cdot y$ or $z = \frac{x}{y}$

$$s_z = z \cdot \sqrt{\left(\frac{s_x}{x}\right)^2 + \left(\frac{s_y}{y}\right)^2}$$

3. Multiplying by constants $z = a \cdot x$

$$s_z = a \cdot s_x$$

4. Linear sum/subtraction $z = x + y$

$$s_z = \sqrt{s_x^2 + s_y^2}$$

5. Exponent of measurement $z = x^a$

$$s_z = a \cdot x^{a-1} \circ s_x$$

6. Logarithms $z = ln(x)$

$$s_z = a \cdot \frac{s_x}{x}$$

7. Exponent by measurement $z = a^x$

$$s_z = s_z \cdot s_x$$