The simulation of the solar system's interplanetary eclipses

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Abstract

This research aims to (1) simulate the motion of solar system objects, (2) simulate the transit of Venus and Mercury in front of the Sun, and (3) simulate interplanetary eclipses in the solar system. Characterization, perspective on the eclipse as a phenomenon and the timing of the occurrence can be predicted by using N-body simulation. To solve the N-body problem, the simulation model is created using the Python 3 programming language and the Leapfrog method. Observing an eclipse as part of a planetary transit of a planet in the solar system from the past to the future or at any given time is included in this work. The results showed that the created model can accurately model the motion of solar system objects. When compared to the database, the created model can represent the previous transit of Venus and Mercury. When the observer's position is changed, the created model can simulate the eclipse as seen from other planets. The results after being compared to the database indicated that the created model can simulate the motion of objects in the solar system with increasing error over time, replicate previous Venus and Mercury transits and simulate the eclipse as seen from another observer's position.

Research background

Eclipses occur naturally when an object moves through a plane and the light source aligns in a straight line with the object and observer. This allows the observer to see the object as a dark shadow that extends beyond the light source. The authors made the decision to investigate this phenomenon by creating a model using computer programming. It can simulate eclipses on planets in the solar system by programming in Python and using the Leapfrog numerical method to solve problems with various objects. To create models that simulate the nature and perspective of the Venus and Mercury eclipse phenomena as seen through the Sun's and other planets' faces in the solar system.

Method

PART1: Simulate the motion of solar system objects.

1. Write a Python modeling program, using NumPy to perform mathematical operations and Matplotlib to draw graphs, for the equations used in the calculations as follows:
   1.1 Newton's law of gravitational
   $$\vec{F} = \frac{Gm_1m_2}{r^3}\vec{r}\,. \quad (1)$$
   1.2 Equation of position and velocity calculation for, "Leapfrog method":
   $$\vec{v}\left(t + \frac{\Delta t}{2}\right) = \vec{v}(t) + \vec{a}(t)\frac{\Delta t}{2} \quad (2)$$
   $$\vec{r}(t + \Delta t) = \vec{r}(t) + \vec{v}\left(t + \frac{\Delta t}{2}\right)\Delta t \quad (3)$$
   $$\vec{v}(t + \Delta t) = \vec{v}\left(t + \frac{\Delta t}{2}\right) + \vec{a}(t + \Delta t)\frac{\Delta t}{2} \quad (4)$$
2. Use the initial positions and initial speeds of solar system objects on January 1st, 2021, 0.00 UT from JPL's HORIZON database.
3. Simulate the model, then compare the model's results, positions, and velocities, to the data in the database and determine the percentage error.

PART 2: Simulate the transit of Venus and Mercury in front of the Sun.

1. Change the initial conditions to January 1st, 2004, 0.00 UT.
2. Translate the position of the solar system with the Sun's position at the center.
3. Rotate the object to be observed around the Y and Z axis, respectively, with the observer's position on the X axis, will find that the view from the planet to the sun is the YZ plane.
4. Convert units from distance to angular distance. to be consistent with the view in the real situation according to equation 6.
   $$\delta = \arctan\frac{d}{2D} \quad (6)$$
5. Simulate Venus and Mercury transiting in front of the Sun and compare the occurrence of the phenomenon to the database.

PART 3: Simulate interplanetary eclipses in the solar system.

Change the initial value in the model to be able to specify the point of view from the observation point to the phenomenon.

Summary

PART 1: Simulate the motion of solar system objects.

The outcomes demonstrated that the developed program can precisely solve the N-body problem and replicate the motion of solar system objects, though there is some error. Increasing the time interval between calculation times, will make the created model less inaccurate.

Part 2: Simulate the transit of Venus and Mercury in front of the Sun.

The transits of Venus and Mercury can be simulated to show the phenomenon as seen from the center of the Earth. The result of the figures compared to the actual events in Figure 1. When comparing data from the simulated result with data from databases, the results show that with increasing time since the initial condition of the selected event, the error of the starting date increases. The absence of other celestial bodies in the solar system that were not included in the simulation, such as asteroids or moons, may also be the cause of the error.

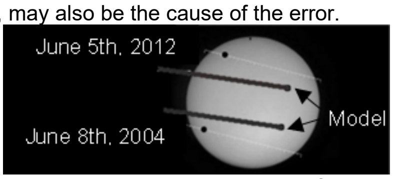

Figure 1 The compared Venus transit result from simulation and real event in 2004 and 2012. (NASA, 2012)

Part 3: Simulate interplanetary eclipses in the solar system.

The results of the interplanetary eclipse are represented in Figures 5 and 6. The study revealed that the model of the Venus and Mercury transit phenomena can be utilized to describe the eclipses of other planets in the solar system since the model developed will display the characteristics of the eclipse from the planets' center of mass. By the way, a spherical shape for the star image in the model was assumed. It cannot simulate the occurrence of the stars that do not have spherical shapes are incompatible with it, such as moon Phobos.

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Reference

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