The Simulation of Interplanetary Motion in Solar System

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Abstract

This project is a simulation of the spacecraft movement between planets in our solar system. The project's goals are to (1) model planet motion in the solar system, and (2) simulate interplanetary spacecraft motion in the solar system with varying initial velocity. Python 3 was used to create the model, which included Euler's approach as well as the Hohmann Transfer Orbit. The database's information on the planet’s positions and orbital velocity were used as initial conditions. The result of the study revealed that the created model can accurately simulate planet motion in the solar system. The largest percentage difference between the planets and the Sun is 1.65% for Venus and Mercury, and the smallest is 0.00028% for Saturn. And for all stars, the average discrepancy is 0.507%. The journey from Earth to Mars takes 192 days in this simulation, with an initial velocity of 33.84 km/s and a speed difference (Δv) of 4.31 km/s.

Introduction

Sending spacecraft is one of the methods scientists use to explore or study objects in the solar system. One method of moving a spacecraft between objects in the solar system is the Hohmann Transfer Orbit, which determines orbits under the influence of the Sun's gravity. At the high school level, physics models can be used to study space exploration. In physics modeling with computer programing Euler's approach is one of the numerical methods that can be used in physics modeling with computer programming. The goal of this study is to use computer programming to create a representation of a spacecraft traveling between objects in the solar system.

Materials and Methods

PART 1: The solar system model

1. Create a model with the Python 3 language and Numpy and Matplotlib modules.
2. Create a function for calculating acceleration. To be used to update acceleration, velocity, and position changes over time (Δt):

$$\vec{a}(t) = \frac{GM_1M_2}{r^3}\vec{r} \quad (1)$$

$$\vec{v}(t+\Delta t) = \vec{v}(t) + \vec{a}(t)\Delta t \quad (2)$$

$$\vec{r}(t+\Delta t) = \vec{r}(t) + \vec{v}(t+\Delta t)\Delta t \quad (3)$$

3. Using the positions and speeds of solar system objects on January 1, 2021, 0.00 UT from JPL's HORIZON database as the default in modeling.
4. Run the simulation using a one-day calculation update period and a 100-year calculation period
5. Compare the model's results, positions, to the data in the database and determine the percentage error.

PART 2: The interplanetary model

1. Create functions and equations for processing spacecraft motion, utilizing Kepler's 2nd law to determine the criteria for a transiting orbit's initial velocity.

$$v_p = \sqrt{\frac{GM_s}{a} \cdot \frac{r_a}{r_p}} \quad (4)$$

2. Using the Tkinter module, write a program to build an interface for making the variation of spacecraft’s initial velocity.

Simulate the journey of a spacecraft from Earth to Mars and Mars to Earth.

Result and Conclusion

PART 1: The solar system model

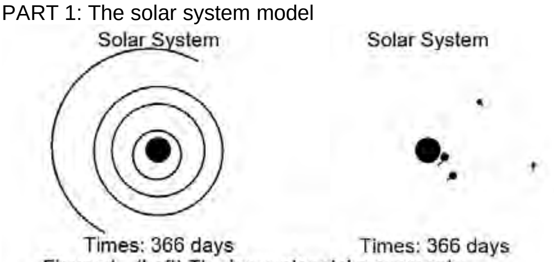

Figure 1 (Left) The inner planets' movements.
(Right) The outer planets' movements.

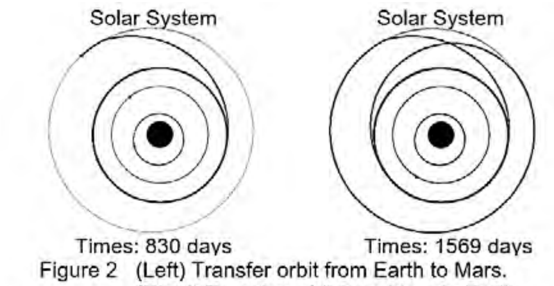

Figure 2 (Left) Transfer orbit from Earth to Mars.
(Right) Transfer orbit from Mars to Earth.

Figure 1 and Figure 2 shows the results of the simulated movements of planets in the solar system. The created model is effective. The reference distance is compared to the simulated one for each object. The largest percentage error between the planets and the Sun is 1.65% for Venus and Mercury, while Saturn has the smallest at 0.00028%. And for all stars, the average discrepancy is 0.507% as shown in table 1. The simulation can be more accuracy by decreasing the time step or reduce the calculation time.

Table 1 The comparisons of percentage error

	Sun	Saturn	Uranus	Jupiter	Neptune
error (%)	2.88×10^{-4}	2.88×10^{-4}	1.47×10^{-3}	3.35×10^{-3}	3.35×10^{-3}
	Mars	Earth	Venus	Mercury	Average
error (%)	1.19×10^{-1}	1.13	1.13	1.65	5.07×10^{-1}

* Sort from the lowest to the highest percentage error.

PART 2: The interplanetary model

The results reveal that the solar system's model of interplanetary spaceship takes 192 days to journey from Earth to Mars and a speed difference (Δv) of 4.31 km/s. However, the orbital plane in z-axis doesn’t consider for this study. So, the result may not be applied to the real situation.

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