Estimating Weight of Moon

There are several methods for estimating the mass of a planet, but the most precise calculations rely several approaches

1. Using Natural Satellites

If a planet has natural satellites, its mass can be determined using Newton's law of universal gravitation. By applying a generalized form of Kepler's third law, which accounts for both the planet's and the moon's mass, we can derive an accurate estimate.

2. Data from Spacecrafts

Observations of spacecrafts around a planet provide highly accurate method for mass estimation. By analyzing the spacecraft's motion and the gravitational influence exerted by the planet, we can determine its mass with great precision.

Variables

I will determine the Moon's mass based on spacecraft orbiting it. This method is highly precise and relatively simple. To calculate the Moon's mass, we need the know following variables:

- **Orbital Radius (r):** The distance from the center of the Moon to the orbiting object.
- **Orbital Speed (v):** The speed at which an object orbits the Moon.
- **Gravitational Constant (G):**

$$G = (6.6743 \pm 0.00015) \times 10^{-11}\,\mathrm{m^3kg^{-1}s^{-2}}$$

Using these values, the Moon's mass can be calculated with the formula:

$$\text{Moon's Mass} = \frac{r \times v^2}{G}$$

Lunar Reconnaissance Orbiter

The Lunar Reconnaissance Orbiter launched on June 18, 2009 to study the Moon and prepare for future human exploration. After reaching the Moon, it began collecting high-resolution data. LRO has mapped the Moon's surface, studied radiation exposure, identified potential landing sites, and investigated lunar resources like water ice. LRO continues to provide valuable data and it will operate until it runs out of fuel and eventually crashes onto the Moon's surface. LRO SPICE data set contains navigation and related observation geometry and other ancillary data in the form of SPICE System kernel files for the LRO spacecraft. By utilizing this data, we can obtain the necessary orbital parameters to accurately calculate the Moon's mass.

SPICE & SpicePy

SPICE is a software toolkit developed at NASA for investigating planetary and spacecraft positions, as well as ancillary engineering information. It is written in FORTRAN 77 and C. SpiceyPy is a community-developed Python wrapper for SPICE, providing an interface between low-level C functions and higher-level Python, IDL, and MATLAB SPICE wrappers. It is widely used in space missions to manage data related to spacecraft positions, orientations, orbits, and time conversions.

Project Structure

```
OrbitAnalysis-LRO
|
├── kernels
│   ├── meta_kernel.tm    # lists all the kernels to load
|   |
│   ├── lsk               # Directory for Leapseconds kernels.
│   │   ├── lskinfo.txt
│   │   └── naif0012.tls  # Leap second file needed for time conversions.
|   |
│   └── spk               # Directory for SPICE ephemeris kernels.
│       ├── spkinfo.txt
│       └── lrorg_2024167_2024259_v01.bsp
|
├── main.py     # Runs the orbit analysis.
└── README.md   # Project documentation.
```

In the SPICE system, **kernels** are specialized files containing data on time conversions, spacecraft trajectories, and celestial positions.

- **meta_kernel.tm**
  This master file lists every other kernel we need. Loading it ensures that all relevant data is available for the analysis.
- **lsk Folder (Leapseconds Kernels)**
  Within this folder, the file **naif0012.tls** is critical. It contains the leap second data required to convert human-friendly UTC times into the uniform ephemeris time that SPICE uses, ensuring our time measurements are accurate.
- **spk Folder (Spacecraft Ephemeris Kernels)**
  Here, the file **lrorg_2024167_2024259_v01.bsp** holds the trajectory data for the Lunar Reconnaissance Orbiter. This SPK file provides the positions and velocities needed to determine the spacecraft's state vector, which is fundamental for calculating orbital parameters.

Calculations

```
import spiceypy as spice
import numpy as np

# Load all necessary kernels
spice.furnsh("kernels/meta_kernel.tm")

# Convert a UTC time string to ephemeris time.
et = spice.utc2et("2024-06-20T00:00:00")
print("Ephemeris time for 2024-06-20T00:00:00 is:", et)

# Retrieve the state vector of the spacecraft relative to the Moon,
# J2000 frame avoids needing Moon-fixed orientation data.
state, lt = spice.spkezr("LRO", et, "J2000", "NONE", "MOON")

# Extract position (km) and velocity (km/s)
pos_km = state[0:3]
vel_kmps = state[3:6]

# Convert position and velocity to meters and m/s
pos_m = np.array(pos_km) * 1000.0
vel_mps = np.array(vel_kmps) * 1000.0

# Calculate the orbital radius and speed.
r = np.linalg.norm(pos_m)
v = np.linalg.norm(vel_mps)

print(f"Orbital radius (r): {r:.2f} m")
print(f"Orbital speed (v): {v:.2f} m/s")

# Gravitational constant
G = 6.67430e-11

# Calculate the Moon's mass using the formula for a circular orbit:
mass_moon = (r * v**2) / G
print(f"Calculated Moon's mass: {mass_moon:.3e} kg")

# Clear loaded kernels.
spice.kclear()
```

Output

```
(venv) archlinux% python main.py
Ephemeris time for 2024-06-20T00:00:00 is: 772113669.1844125
Orbital radius (r): 1850335.11 m
```

```
Orbital speed (v): 1617.86 m/s
Calculated Moon's mass: 7.256e+22 kg
```

Overall Error

The estimated mass of the Moon is very close to the widely accepted value of **7.34×10^{22} kg**. Our calculation gives a result that is about **1.24% difference**. This small difference is due to assumptions in our calculation. We used a simplified formula and assumed the Moon follows a perfectly circular orbit based on a single moment in time. In reality, the Moon's orbit is slightly elliptical and influenced by other factors, leading to minor variations in the computed mass.

Results

Hypothetically, if we placed the Moon on Earth, we could calculate its weight using Earth's gravity.

$$\text{Moon Weight} = \text{Moon Mass} \times \text{Earth Gravity}$$

$$\approx (7.35 \times 10^{22}\,\text{kg}) \times (9.81\,\text{m/s}^2)$$

$$\approx 7.21 \times 10^{23}\,\text{N}$$

if we calculate its weight using the Moon’s own gravity:

$$g_{\text{Moon}} = 1.625\,\text{m/s}^2$$

$$\text{Weight on Moon} = (7.35 \times 10^{22}\,\text{kg}) \times (1.625\,\text{m/s}^2)$$

$$\approx 1.19 \times 10^{23}\,\text{N}$$

Conclusion

Using spacecraft data and gravity laws can accurately estimate a planets mass. By applying SPICE and SpicePy tools to obtain orbital parameters, calculating the Moon’s mass to be very close to the accepted value. Despite small simplifications, this approach provides effective for understanding planetary masses and highlights the importance of precise data and analysis in space research.

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Assignment 2

Weather Prediction & Supercomputing

Onur Onel – 0865803
Dr. Sabine McConnell

Trent University
BSc. Software Engineering
COIS 1400

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Weather Prediction & Supercomputing

In absolute deterministic systems, having all the necessary initial data allows us to predict the future precisely. Examples of such deterministic systems include mathematical structures such as functions and algorithmic processes which always produce the same result over infinitely many iterations (MakeUseOf 2021). However, in the physical world, I would say these systems are partially deterministic, for example, weather prediction, finance and economics, ecological systems and biology, as well as social sciences. Chaos theory states these deterministic systems are highly sensitive, even the smallest variations can lead to vastly different outcomes known as the butterfly effect, making %100 precise predictions impossible (ScienceDirect 2003). However, scientists leverage these systems' deterministic nature to make highly accurate predictions. To develop accurate weather predictions, meteorologists gather data from all around the world to train models that process and compare them with historical records and calculations. Each model specializes in a particular area of the weather systems and runs simultaneously (MakeUseOf 2021).

Weather prediction requires processing vast amounts of diverse data and simulating complex, chaotic interactions at high resolution. These tasks involve solving numerous equations simultaneously in a very short time. Statistical models use data analysis rather than simulating weather patterns In contrast, Climate models use simulations which are primarily used to predict long-term changes in the climate. Prediction models are integrated into digital simulations of the Earth's atmosphere, where time is accelerated to estimate upcoming weather conditions on a global scale (MakeUseOf 2021). Current weather forecasting models achieve 90 percent accuracy for predictions up to five days ahead. However, accuracy declines beyond this point, dropping to 80 percent for seven-day forecasts and approximately 50 percent for forecasts extending further into the future (MakeUseOf 2021). To ensure frequent and precise forecasts, meteorology centers rely on powerful supercomputers.

National Oceanic and Atmospheric Administration’s operational supercomputing systems, Dogwood and Cactus, are twin supercomputers located in Manassas, Virginia, and Phoenix, Arizona. The system operates at a speed of 50 petaflops in total, enabling 50 quadrillion calculations per second (NOAA 2023). In September 2024, NOAA introduced Rhea, which is equipped with advanced GPUs designed to enhance NOAA’s use of artificial intelligence and machine learning applications, including marine life monitoring, weather forecasting, and modelling environmental events such as atmospheric rivers, fire weather, and hurricane intensification. The integration of Rhea will add approximately 30 petaflops of computational speed, bringing NOAA’s total research and development capacity to around 80 petaflops equivalently 80 quadrillion calculations per second (NOAA 2023).

Supercomputers are extremely powerful machines containing numerous interconnected processors operating simultaneously. Their hardware includes high-speed CPUs and data center GPUs, along with vast amounts of high-speed memory and storage systems. These components are connected via high-speed networks, enabling efficient data sharing. On the software side, specialized operating systems typically kernel-modified LinuxOS for direct hardware access, managing the processors using optimized compilers to fully leverage the hardware's capabilities (Dayley, 2023). National Oceanic and Atmospheric Administration's computing infrastructure consists of computer nodes that process vast amounts of weather data. In 2023, smarter memory organization and enhanced scheduling boosted processing speeds by 25%. Additionally, optimized routing reduced communication delays by nearly 30% and NOAA integrated AMD Instinct APUs, which combine CPUs and GPUs into a single unit (Data Center Dynamics, 2023) Furthermore, a new memory architecture utilizing CXL 3.0 technology is expected to accelerate data processing and improve memory efficiency. On the software side, NOAA's Unified Forecast System underpins its weather simulations (Data Center Dynamics, 2023). UFS v5.0 incorporates artificial intelligence to continuously refine forecast models, and advanced workflow tools will enable the system to run multiple simulations concurrently, ensuring that operations remain fast, stable, and energy efficient(GDIT, 2023).

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