Moon-based visibility analysis for the observation of “The Belt and Road”

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ABSTRACT: Aiming at promoting the economic prosperity and regional economic cooperation, the “Silk Road Economic Belt” and the “21st Century Maritime Silk Road” (hereinafter referred to as the Belt and Road) was raised. To get a better understanding of “the Belt and Road” whole region, considering the large-scale characteristic, the Moon platform is a good choice. In this paper, the ephemeris is taken as data source and the positions and attitudes of Sun, Earth and Moon are obtained based on the reference systems transformation. Then we construct a simplified observation model and calculate the spatial and angular visibility of the Moon platform for “the Belt and Road” region. It turns out that Moon-based observation of this region shows a good performance of spatial visibility and variable angular visibility, indicating the Moon being a new potential platform for large-scale Earth observation.

1. Introduction

When Chinese President Xi Jinping visited Central Asia and Southeast Asia in 2013, he raised the initiative of jointly building the Belt and Road, which has attracted close attention from all over the world. The Belt and Road Initiative aims to promote the connectivity of Asian, European and African continents and their adjacent seas, establish and strengthen partnerships among the countries along the Belt and Road, set up all-dimensional, multi-tiered and composite connectivity networks, and realize diversified, independent, balanced and sustainable development in these countries. However, the existing Earth observation systems lack the ability of long-term continuous observation at a regional-to-global scale due to the spatial and temporal coverage limitation and systematic bias of satellite observation [1]. Under this circumstance, Guo proposed to probe into ways of setting up observatory on
the moon containing a group of remote sensors as a complement for global environmental change on a global scale [2]. In order to get a better understanding of “the Belt and Road” region, considering the spatial and angular visibility, we propose the Moon platform for observation.

Taking the Moon as a platform for Earth observation has several potential advantages [3]–[5]: (1) the Moon is a satellite that never falls and its microgravity facilitates the installation, upgrading, maintenance and replacement of large telescopes, antenna arrays and other equipment. (2) The Moon's rotation period and revolution period are the same, with one side always facing the earth, and therefore, it is possible to observe a certain area of the Earth over a long period of time from a variable angle. (3) Since the geological structure of the Moon is very stable, the sensors mounted on it are much more stable than those on near-earth satellites.

In this paper, we construct a simplified observation model and calculate the spatial and angular visibility of the Moon-based observation for “the Belt and Road” region in order to quantificationally evaluate the visible ability of the Moon platform.

2. Data and processing

2.1 Study area

As is shown in the fig.1, “the Belt and Road” includes the “Silk Road Economic Belt” and the “21st Century Maritime Silk Road”, covering three continents: Asia, Europe and Africa. Approximately, we make use of the locations of several cities to set the boundary of this region, such as Ningbo (29°53'N 121°33'E), Djakarta (6°08'S 106°45'E), Nairobi (1°17'S 36°49'E), Rotterdam (51°55'N 4°29'E), Moscow (55°45'N 37°37'E) and Xi'an (34°16'N 108°57'E).

2.2 Data source

The ephemeris data from Jet Propulsion Laboratory (JPL) is used in this study. JPL ephemerides of DE series are the most popular ephemerides among the international astronomical community, providing the positions and velocities of certain celestial bodies at a given time, generated by fitting numerically integrated orbits of the Moon and planets to observations[6]. The positions and velocities are stored as Chebyshev interpolation polynomial coefficients fit in 32-day-long segments, which are shown in the
form of planetary three-dimensional Cartesian reference of heliocentric reference system[7].

2.3 Data processing
As is shown in the fig.2, there are several data processing steps: (1) Read the ephemeris’ header files and data files, and then merge each part of them chronologically. (2) Based on the given Julian time, obtain the corresponding ephemeris data, then calculate the positions and velocities of each celestial body by interpolation. (3) According to the observational perspectives of simulation, reference systems transformations are carried out.

First, time system is introduced. Julian day is the continuous count of days since the beginning of the Julian Period. The Julian date (JD) of any instant is the Julian day number for the preceding noon in Greenwich Mean Time plus the fraction of the day since that instant. Julian dates are expressed as a Julian day number with a decimal fraction added. The Julian Period is a chronological interval of 7980 years beginning 4713 BC. It has been used by historians since its introduction in 1583 to convert between different calendars.

Besides, there are a few reference systems related to the Moon-based Earth observation. It is essential to bridge the different reference systems for calculating the celestial bodies’ positions from different perspectives [8]. When celestial spheres’ centers are selected as the center of Sun, Earth or Moon, three different celestial reference systems are defined: heliocentric celestial reference system (HCRS), geocentric celestial reference system (GCRS) and selenocentric celestial reference system (SCRS). In addition, it is necessary to utilize the international terrestrial reference system (ITRS) when dealing with the parameters related to Earth [9]. Analogously, principal axis lunar reference system (PALRS) is introduced for the parameters related to lunar surface [10].

2.4 Calculation of visibility
As the lunar radius is much lesser than the distance between Moon and Earth, we utilize the barycentre of Moon to take the place of the observatory’s position for simplification. From the preceding processing, the coordinates of lunar barycentre $L(x_L, y_L, z_L)$, Sun $H(x_H, y_H, z_H)$ and the target on Earth $T(x_T, y_T, z_T)$ could be obtained. Thus, the visibility of the target could be derived:

$$\alpha = \arccos \left( \frac{x_L x_T + y_L y_T + z_L z_T}{\sqrt{(x_L^2 + y_L^2 + z_L^2)(x_T^2 + y_T^2 + z_T^2)}} \right)$$  (1)

$$\beta = \arccos \left( \frac{x_T x_H + y_T y_H + z_T z_H}{\sqrt{(x_T^2 + y_T^2 + z_T^2)(x_H^2 + y_H^2 + z_H^2)}} \right)$$  (2)

$$\alpha < \frac{\pi}{2} \text{ & } \beta < \frac{\pi}{2}$$  (3)

If formula (3) condition is met, the target is visible. Then the observing perspective $\theta$ is:

$$x_D = x_L - x_T, \quad y_D = y_L - y_T, \quad z_D = z_L - z_T$$  (4)

$$\theta = \arccos \left( \frac{x_T x_D + y_T y_D + z_T z_D}{\sqrt{(x_D^2 + y_D^2 + z_D^2)(x_T^2 + y_T^2 + z_T^2)}} \right)$$  (5)

3. Results and analysis
After a lot of experiments, we find that there is similarity between different months with little difference. So we arbitrary choose the data in May, 2016 for description. Since the Moon-based Earth observation
is continuous, Rotterdam and Ningbo, the two terminal vertexes of the “the Belt and Road”, are selected for analysis.

As is shown in the fig.3, the observation period in a day of Rotterdam is a bit longer than that of Ningbo. They both show similar variation trend. The observation period of Rotterdam varies between 870 minutes and 40 minutes and that of Ningbo varies between 750 minutes and 40 minutes. The average period of these two targets are 446.77 minutes and 390.65 minutes, showing a good performance of visibility.

The fig.4 shows the observation period of the “the Belt and Road” in each day of May, 2016. The “whole” curve refers to the whole region of “the Belt and Road” could be observed and the “region” curve refers to any region of “the Belt and Road” could be observed. The average period of these two categories are 80.65 minutes and 756.77 minutes, indicating a rather good coverage of the study area.

The fig.5 and fig.6 depicts the perspective from Moon platform of Rotterdam and Ningbo, showing that the perspective of Rotterdam is larger than that of Ningbo, owing to the relative positions of Moon and Earth and the latitudes of Rotterdam is larger than Ningbo. The perspective of Rotterdam varies between 34° and 90° and that of Ningbo varies between 10° and 90°. Analogously, the cities with smaller latitudes have larger perspective variation. Thus, for “the Belt and Road” region, different cities with different latitudes differ a lot at the perspective. Besides, it is obvious too large the perspective is not suitable for observation. Although at the certain time, some region is visible from the Moon platform in theory, it is possible that the perspective is too large, which is not appropriate for observation.
Actually, there is a little difference between different months for observing periods and perspective since the Moon has libration. Besides, the period of lunar rotation is one sidereal month, not synodic month. Because of the different time system, it brings the difference. In addition, the axis perpendicular to the lunar orbit’s plane precess clockwise in the ecliptic, the period of which is 18.6 years. Correspondingly, the observing periods and perspective vary in different years, which adds to more diversity. Generally, the observing periods of low latitudes’ locations are more stable than that of high latitudes’ locations in different months and the perspective of low latitudes’ locations has a larger range than that of high latitudes’ locations.

4. Conclusion
This paper, facing the demand of observation of “the Belt and Road” region, proposed Moon-based platform for large-scale observation. The JPL ephemeris is selected as data source and processing procedures are introduced. The spatial and angular visibility of this region is calculated with the average period of whole region of 80.65 minutes in a day and the average period of any part of the region of 756.77 minutes, implying a good performance of overall observation. For angular visibility, the perspective vary a lot for different latitudes, showing a large range of variable angular visibility characteristic. Furthermore, the perspective of low latitudes’ locations has a larger range than that of high latitudes’ locations. However, for certain target, the perspective should be carefully chosen for effective observation, avoiding large distortion.

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