PRELIMINARY EVALUATION OF RADIO DATA ORBIT DETERMINATION CAPABILITIES OF CHINA'S FIRST LUNAR ORBITER

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ABSTRACT

Orbit determination accuracies with radio tracking of China's first lunar orbiter (Chang'e-I) have been investigated. The challenge is that China has no global deep space network. Furthermore, two stations couldn't take rang and range-rate data simultaneously due to the platform's capability. The orbit determination will mostly be based upon a short arc of data observed by a single station and no differenced radio data could be employed. To obtain preliminary estimates of such radio navigation capabilities, simulations has been carried out with batch filtering of conventional radio data from separated stations. Analysis results indicate that navigation accuracy is associated with the geometry of the ground stations. Therefore the orbit determination capabilities could be enhanced with the availability of overseas stations' radio data.

1. INTRODUCTION

China is planning a three-phase Moon program: orbiting, landing, and returning from the Moon. In the first phase, a lunar orbiter, Chang'e-I, named after a famous Chinese fairy, will be send to the lunar polar orbit, circling the moon and mapping its surface. In the mission design, it is necessary to evaluate the navigational capabilities associated with the ground tracking system.

Deep space radio tracking relied solely upon Doppler and range systems in the early deep space explorations [1]. Though tracking of vehicles at lunar distances could be accomplished through a variety of radio and optical techniques, the radio data are still the main type of tracking data. The Lunar Prospector mission succeed in trajectory operation and updated the lunar gravity model mainly with the range and Doppler data provided by the Deep Space Network (DSN) located in California, Australia, and Spain [2].

The navigation of Chang'e-I will also mainly rely on the range and Doppler data. However, there are still some challenges for China to perform the trajectory operation for its first lunar orbiter.

China has no deep space network. As a result of the project cost limit, the space operation of China's first lunar exploration project will be undertaken by the Unified S-Band (USB) system, which is mainly designed for the manned space flight [3]. Though the system has provided the wide coverage and reliable TT&C and Communication services for Shenzhou-5 manned spaceship, it has only three 12-meter-antennas which receive the signal transmitted from 400,000 kilometers far away. It could not provide the 100% coverage for the Earth-to-Moon transfer trajectory.

And two stations couldn't take rang and Doppler data simultaneously due to the platform's capability. Therefore, the orbit determination will mostly be based upon the data observed by one station and no differenced radio data could be employed.

In additional, the radiometric tracking at S-band is single-frequency downlink. It is not available to use the differenced data to reduce the effects of the ionosphere and solar plasma.

Under the above constraint conditions, the preliminary evaluation of radio data orbit determination capabilities of Chang'e-I has been performed. The strategy of orbit determination for various phases are not similar. The precise orbit determination for lunar polar orbiter has been discussed formerly [4]. In this paper, the orbit determination capabilities of the trans-lunar trajectory are reported.

2. ERATH-TO-MOON TRAJECTORY OF CHANG'E-I

A view of orbit design for Chang'e in on-orbit configuration is shown in Figure 1.

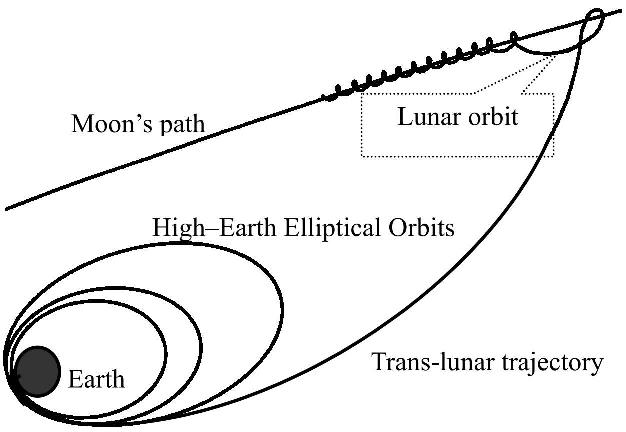

Fig. 1 Earth-to-Moon Trajectory of Chang'e-I

LM-3 rocket will boost Chang'e-I into ultra-high elliptical orbit with a 31-degree inclination and a 200-km perigee. Several impulse thrusts (Δv_i) will be executed until the spacecraft could be injected into its nearly five-days trans-lunar trajectory [5][6]. During the cruise phase, two or three midcourse corrections are necessary [7]. At the nearest approach to the Moon, a serial of Hohmann transfers will be executed to reduce the velocity and put the spacecraft into the lunar circular polar orbit. Chang'e is hoped to work in this orbit more than one year.

A trans-lunar trajectory is given by paper [7]:

Insert epoch: 02:50:00 2004-08-27

End epoch: 02:50:00 2004-09-01

Earth-to-Moon Transfer time: 120 hours

Velocity at the perigee: 10.5946 km/s

RA of ascend Node: 7.9996°

Argument of perigee: 180.2144°

The trans-lunar trajectory was divided into three arcs by two mid-course corrections, signed as TLI1, TLI2, and TLI3. The first mid-course correction was planed in the 24 hours after the orbit insert, and the second one was planed 24 hours before the satellite captured by the moon.

3. GROUND TRACKING SYSTEM

Figure 2 illustrated the ground tracking system for Chang'e-I. The Chinese ground network, including two stations in the mainland and one vessel located in the Pacific, is illustrated. Kashi is located the Northwest China. Nanning is located in the Southeast China. A vessel, called Yuanwang, will be located in the Pacific. Besides these stations, three overseas ground stations are simulated to tracking the lunar orbiter, which are Villafranca, New norcia, and CEE of Chile. The 9-m antenna of CEE is only available in the early trans-lunar trajectory, TLI1.

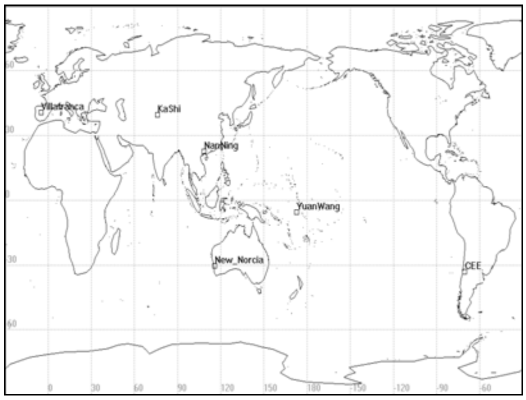

Fig. 2 Ground Network

The access time between the Chinese ground station system and the global system are illustrated in Figure 3.

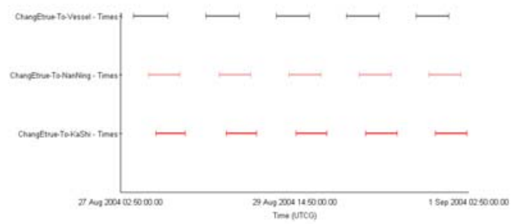

Fig. 3(a) Access Time

(of the Chinese ground network)

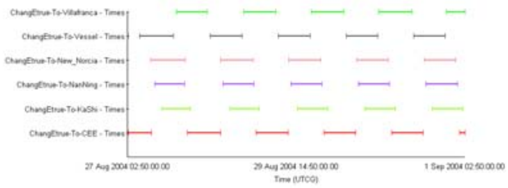

Fig. 3(b) Access Time

(of the global ground network)

4. METHODOLOGIES

In the difference phases of Chang'e-I, the motion of the spacecraft could be represented in the different equations. [8][9]. For the trans-lunar phase, the equation of the satellite motion is represented as an initial problem of the differential equation in ECI, i.e.,

$$\begin{cases} \ddot{\vec{r}} = \vec{F}_e(\vec{r}) + \vec{F}_m(\vec{r}) + \vec{F}_\varepsilon(\vec{r},t) \\ t_0 : \vec{r}(t) = \vec{r}_0, \dot{\vec{r}}(t) = \dot{\vec{r}}_0 \end{cases} \quad \bullet 1 \bullet$$

where $\vec{r}$, $\dot{\vec{r}}$, and $\ddot{\vec{r}}$, respectively, represent the position vector, the velocity vector and the acceleration vector of the satellite in the Mean of J2000.0 coordinate system. $\vec{F}_e(\vec{r})$ is the earth central gravity, $\vec{F}_m(\vec{r})$ is the lunar central gravity, $\vec{F}_\varepsilon$ includes the accelerations due to the perturbations.

Supposed the tracking data are the range and Doppler data. The relationship between the observation vector Y and the state vector X is represented as

$$Y = \begin{pmatrix} \rho \\ \dot{\rho} \end{pmatrix} \quad \bullet 2 \bullet$$

where

$$\rho(\vec{r},\vec{R}) = \left|\vec{r} - \vec{R}\right| \quad \bullet 3 \bullet$$

and

$$\dot{\rho} = (\vec{r} - \vec{R}) \cdot (\dot{\vec{r}} - \dot{\vec{R}}) \quad (4)$$

5. SIMULATION AND RESULT

To obtain preliminary estimates of such radio navigation capabilities, analyses were performed based upon the two types of radio data. The simulation has been carried out with the batch filtering of conventional radio data from stations considering the effects of error sources. The stations are supposed tracking in sequence.

In addition to the measurement bias and noise, the solutions is also sensitive to the following error sources [10]:

(1) Data coverage

(2) Length of data arc

(3) Constant station location errors

(4) Constant and stochastic spacecraft accelerations

(5) A priori knowledge of the lunar ephemeris

In Table 1, the errors sources considered are listed.

Table 1 Errors sources

Error sources			Magnitude	estimated
Data error	range	bias	10m	yes
		noise	10m	
	Doppler	bias		
		noise	5cm/s	
Station location error	only for Vessle	constant	10m	yes
Spacecraft acceleration	along track	Constant	10×10^{-12} m/s^2	no
Lunar ephemeris error			Not considered	

Firstly, the effect of data coverage and length of the data arc are analyzed. The orbit solution errors in position for TLI1, TLI2 and TLI3 are showed in Figure4, Figure5 and Figure6 respectively, where a is the solution of the data tracked by the Chinese ground network and b is the solution of the data tracked by the global ground network. The tracking geometry of the global ground network is better than the Chinese ground network. And the length of data arc is extended. For all the three phases of the lunar trajectory, the solutions of the global tracking system are obviously better than those of the Chinese ground system. The accuracies are doubled or even improved more than one order.

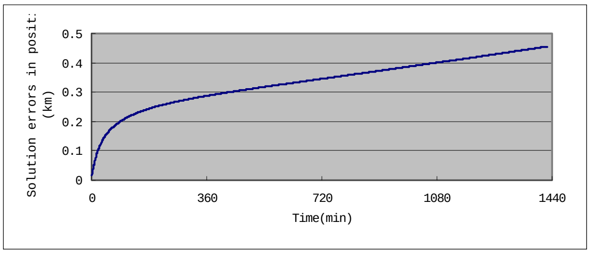

Fig. 4(a) Solution errors in position of TLI1

By the Chinese ground network

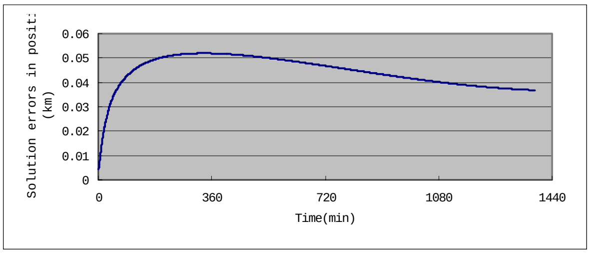

Fig. 4(b) Solution errors in position of TLI1

By the global ground network

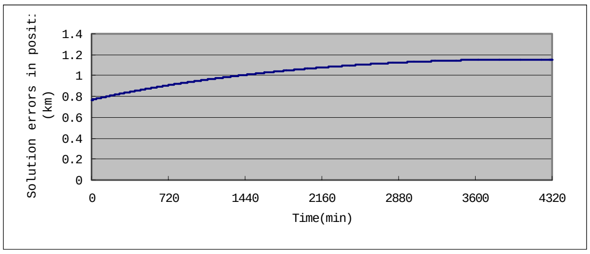

Fig. 5(a) Solution errors in position of TLI2

By the Chinese ground network

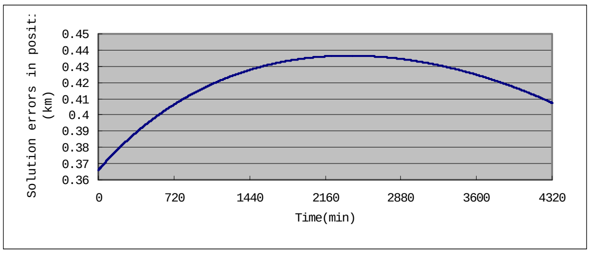

Fig. 5(b) Solution errors in position of TLI2

By the global ground network

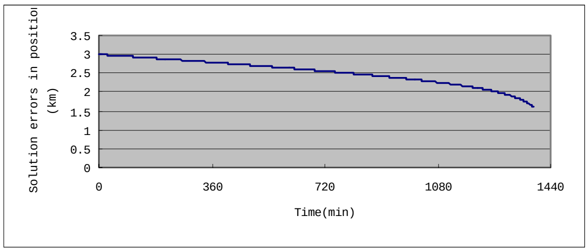

Fig. 6(a) Solution errors in position of TLI3

By the Chinese ground network

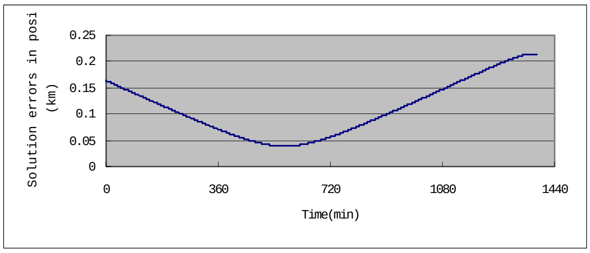

Fig. 6(b) Solution errors in position of TLI3

By the Chinese ground network

Secondly, the orbit determination capabilities of the two types of tracking data are analyzed. The solution error of TLI1 is showed in Figure 7, where a is the solution of range data only and b is the solutions of Doppler data only. It could be concluded that the accuracy of Doppler data of the Chinese facilities are much worse than that of the range data.

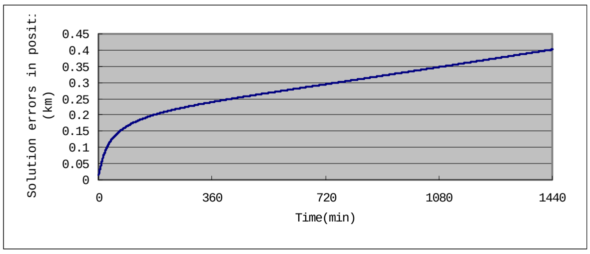

Fig. 7(a). Solution errors in position of TLI1

(range data of the Chinese network only)

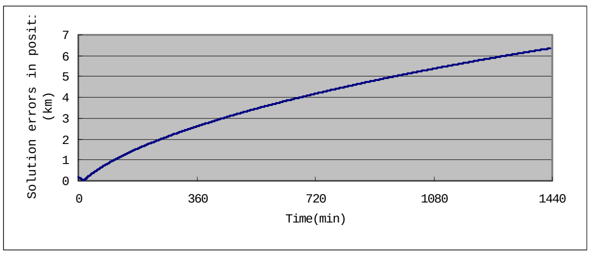

Fig. 7(b). Solution errors in position of TLI1

Doppler data of the Chinese network only

The effects of constant unmodeled spacecraft acceleration and the station location error are also analyzed. Figure 8(a) and 8(b) are the solution errors in position. As the station location error couldn't be solved entirety, its effect is obvious.

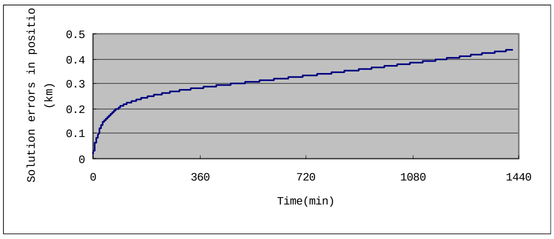

Fig. 8(a). Solution errors in position of TLI1

with unmolded acceration

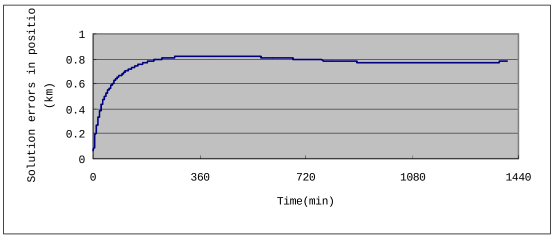

Fig. 8(b). Solution errors in position of TLI1

with unmolded acceration

6. CONCLUSIONS

Simulation results indicate that navigation accuracy is associated with the geometry of the ground stations and the length of the tracking arc. Therefore the orbit determination capabilities could be enhanced with the availability of radio data tracked by oversea stations. It has been within the system design consideration using the overseas deep space facility to enhance the reliability and the support ability of the space operation for the Chang'e project [11].

In order to guarantee the flight path of the Chang'e and provide the precise navigation during its initial flight period around the moon, the Chinese astronomical observation VLBI system is also introduced besides using USB to measure the range and Doppler to achieve the proposed precise orbit required by the scientific instruments [11]. In Chinese VLBI system, four antennas provide two approximately orthogonal baselines for satellite positioning. The Evaluation of orbit determination capabilities of these two systems combined will be reported later.

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