Study on Large-scale Dynamic Measurement of Lunar Rover with iGPS

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Abstract. In the motion simulation test, the real-time position and orientation of lunar rover need to be measured accurately in a wide area to test lunar rover's motion performance on simulated lunar soil. The iGPS system, whose accuracy is better than 1mm and sampling frequency is higher than 10 Hz, is applied to measure the position and orientation of lunar rover in the test. Large-scale dynamic measurement of lunar rover with iGPS is studied in this paper. This paper mainly discusses the layout methods of laser transmitters and receiving sensors, and analyzes the position and orientation measurement accuracy of different layout methods to achieve optimization layout. It can provide some reference for the research of large-scale dynamic measurement of other rigid objects.

1. Introduction
In order to ensure lunar rover’s performance in the process of lunar exploration, a simulation test is carried out on the ground to test lunar rover's motion performance on simulated lunar soil[1]. The position and orientation of lunar rover need to be measured accurately, and then compared with the data of the lunar rover’s guidance navigation and control system to test its mobile control performance. Meanwhile, the position and orientation of lunar rover need to be transmitted to the lunar rover in real time as data input to test its position and orientation determination performance[2]. Large-scale dynamic measurement of lunar rover with iGPS is studied in this paper. The optimization layout methods of laser transmitters and receiving sensors are mainly discussed.

2. Selection of Measuring Scheme
The dynamic measurement of lunar rover’s position and orientation has the characteristics of large-scale, high-precision, real-time, complex motion state. Indoor position and orientation measurement methods mainly include total station system, laser tracker system, photogrammetry system and iGPS system[3].

The total station system requires the tracking target to remain stationary during measurement, and has delays. The laser tracker system can only measure one target ball once, and will not be able to continue tracking measurement if there is a break of light in the measurement process. The photogrammetry system requires a large number of cameras to achieve a wide range of measurement, and the static measurement accuracy is not high enough. The iGPS system is a factory-wide measuring, positioning and tracking system, which is characterized by large-scale, high-precision and high-
frequency. Therefore the iGPS system is the most suitable measuring scheme for large-scale dynamic tracking measurement. The Metris iSpace iGPS system[4], whose accuracy is better than 1mm and sampling frequency is higher than 10 Hz, is applied to measure the position and orientation of lunar rover in the motion simulation test.

3. Design of measuring scheme
The iGPS system is mainly composed of laser transmitters and receiving sensors[5]. The transmitters activate a measurement field with laser signals as large as an entire room or facility. The receiving sensors’ position is calculated by the laser signals received from transmitters. Before measurement, several laser transmitters should be arranged to cover the testing room with laser signals, and several receiving sensors should be installed on lunar rover to receive laser signals. When the lunar rover moves into the testing room, the receiving sensor on the lunar rover will receive the laser signal in real time to complete the measurement.

3.1. Layout of laser transmitters
The layout of the laser transmitter needs to be designed to make the laser signals cover the whole measurement room, and make the signal intensity in any area basically the same. The maximum measuring distance of laser transmitter is 50m, the maximum measuring azimuth is $-145^\circ \sim 145^\circ$, and the maximum measuring elevation is $-30^\circ \sim 30^\circ$, as shown in figure 1.

At least two transmitters are needed to calculate the position of the receiving sensor, which can receive the different laser signals from these transmitters at the same time. Extra transmitters increase the positional accuracy of receiving sensors as better triangulation possible. The line-of-sight between laser transmitters and receiving sensors should be unblocked, otherwise partial or global occlusion of the signals will cause errors or drifts in data calculation.

The layout of the laser transmitters mainly involves its number, relative height and relative angle.

3.1.1. Number. Limited by the optimal measurement range and intersection angle, the number of laser transmitters is mainly determined by the size and shape of the measurement area.

The number of laser signals received at the same time will directly determine the positional accuracy of receiving sensors, as shown in figure 2. When only two laser transmitters cover a measuring point at the same time, the measurement accuracy can only reach 1.5mm (3σ). When three laser transmitters cover the measuring point at the same time, the measurement accuracy can reach 0.535mm (3σ). When four laser transmitters cover the measuring point at the same time, the measurement accuracy can reach 0.375mm (3σ). But when more than four laser transmitters cover the measuring points at the same time, the measuring accuracy is basically not increased. Therefore, in
order to achieve high-precision measurement in the whole area, which is better than 0.375mm, any measuring point in the measurement area should receive laser signals from at least four laser transmitters at the same time.

![Figure 2. The measurement accuracy of iGPS with different numbers of laser transmitters](image)

3.1.2. Height and angle. Mainly limited by the maximum measuring elevation of laser transmitters, \(-30^\circ \sim 30^\circ\), the relative height and angle of laser transmitters should be arranged to cover the whole area with laser signals evenly in the vertical direction. Laser signals from at least two laser transmitters can be received at any measuring point within the measuring range.

3.2. Layout of receiving sensors

Within the measurement area, an unlimited number of receiving sensors can operate concurrently. To meet different measurement requirements, there are mainly four different structures of receiving sensors that can be chosen, which are Single Detector, Mini Vector Bar, Handheld Vector Bar and Handheld iProbe, as shown in figure 3. Single Detector and Mini Vector Bar are fixed measurement sensors, mainly suitable for dynamic measurement. Handheld Vector Bar and Handheld iProbe are mobile measurement sensors, mainly suitable for static measurement. Mini Vector Bar has twice as many sensors as Single Detector, so Mini Vector Bar is mainly used in dynamic measurement of large-scale and complex motions.

![Figure 3. The four different structures of receiving sensors](image)
receiving sensor should be as far as possible. Generally, the receiving sensor should be located on the outermost side of lunar rover. Furthermore, the line-of-sight between receiving sensors and laser transmitters should be unblocked as far as possible during the movement.

4. Measurement accuracy

4.1. Position measurement accuracy
According to the typical measurement accuracy of iGPS system[4], the dynamic position measurement accuracy of lunar rover is 0.375m (3σ). The accuracy of the iGPS system is uniform across the entire measurement volume, regardless of the size of the metrology enabled area.

4.2. Orientation measurement accuracy
The orientation measurement accuracy of the lunar rover is mainly determined by position measurement accuracy and the spacing of receiving sensors. The receiving sensor is isotropic, so the measurement model of the receiving sensor can be simplified to two-dimensional, as shown in figure 4.

\[
\theta = \arctan((y_2 - y_1)(x_2 - x_1)^{-1})
\]

\[
x_1^2 + y_1^2 = \Delta r^2
\]
\[
(x_2 - r)^2 + y_2^2 = \Delta r^2
\]

Then

\[
\theta = \arctan(((\Delta r^2 - (x_2 - r)^2)^{1/2} + (\Delta r^2 - x_2^2)^{1/2})(x_2 - x_1)^{-1})
\]

\[
\theta_{\text{max}} = \arctan(2\Delta r(r^2 - 4\Delta r^3)^{-1/2})
\]

Therefore, if the orientation measurement accuracy is required to be better than 0.1°, the distance between sensors should be more than 429.72mm. If the orientation measurement accuracy is required to be better than 0.01°, the distance between sensors should be more than 4297.2mm. The relationship between orientation measurement accuracy and receiving sensor spacing is shown in figure 5.
4.3. Environmental factors
The main environmental factors affecting the measurement accuracy of iGPS system are vibration, infrared light interference, temperature and air pressure. Vibration will directly affect the calibrated location of the laser transmitters and the parameters of the rotating head, and cause displacement and drift of the laser transmitters. The influence of infrared light on measurement system will become significant with the increase of measurement distance. Temperature and pressure will affect the optical system[3].

5. Application
The site topography of the motion simulation test is shown in figure 6. The left half of the test site is a rectangular experimental area, 15m*30m. The right half is a semi-circular test area with a diameter of 30m. There are three slopes in the test site, with a maximum slope of 20° and a maximum height of 2m. Four laser transmitter stations are installed outside the test site. These stations have different installation heights, ranging from 1.5m to 3.5m, and installation angles, ranging from -30° to 0°.
The simplified configuration of lunar rover is shown in figure 7. The overall dimension of lunar rover is about 1.5mm*1m*1m. Four Mini Vector Bars are installed on lunar rover as dynamic tracking unit. The redundancy design of eight receiving sensors is applied to ensure the stability and reliability of the dynamic measurement. Each spacing between the Mini Vector Bars is over 0.5m to ensure the accuracy of orientation measurement, better than 0.1°.

![Figure 7. The layout of receiving sensors on lunar rover](image)

**6. Summary**

iGPS system has great application prospects in the field of large-scale, high-precision, high-frequency dynamic measurement. In this paper, the dynamic measurement of lunar rover with iGPS is studied. The layout methods of laser transmitters and receiving sensors are emphatically discussed. The measurement accuracy of different layout methods is analyzed. It can provide some reference for the research of large-scale dynamic measurement of other rigid objects.

**Reference**

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