

The Analysis of Moonborne Cross Track Synthetic Aperture Radar Interferometry for Global Environment Change Monitoring

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Abstract: Faced to the earth observation requirement of large scale global environment change, a SAR (Synthetic Aperture Radar) antenna system is proposed to set on Moon's surface for interferometry in this paper. With several advantages superior to low earth orbit SAR, such as high space resolution, large range swath and short revisit interval, the moonborne SAR could be a potential data resource of global changes monitoring and environment change research. Due to the high stability and ease of maintenance, the novel system is competent for offering a long and continuous time series of remote sensing imagery. The Moonborne SAR system performance is discussed at the beginning. Then, the peculiarity of interferometry is analyzed in both repeat pass and single pass cases. The chief distinguishing feature which is worth to research the potentiality of repeat pass interferometry is that the revisit interval is reduced to one day in most cases, and in worst case one month. Decorrelation deriving from geometry variety is discussed in detail. It turns out that the feasibility of moonborne SAR repeat pass interferometry depends on the declination of Moon. The severity of shift effects in radar echoes increased as Moon approaches to the equatorial plane. Moreover, referring to the single pass interferometry, two antennas are assumed to set on different latitude of Moon. There is enough space on Moon to form a long baseline, which is highly related to the interferogram precision.

1. Introduction

As a natural satellite of Earth, Moon is our nearest neighborhood, and also the only extraterrestrial celestial body that human has arrived. In recent years, the returning of the Moon is gaining an increasing interest. Several space agencies propose their ambitious lunar missions in which a manned observatory with stable power source on Moon is of great importance. In fact, setting equipment on Moon for earth observation is not a new idea. It can be traced back to the 1972 when a far-ultraviolet camera/spectrograph experiment was operated on the lunar surface during the Apollo 16 mission. Since then, there are lots of constructive ideas and system configurations being presented. Synthetic aperture radar (SAR) is an active microwave imaging sensor with ability to work in all time and in all weather. Moreover, its spatial resolution is not constrained by the distance from the target. Thus, the far observation distance between Earth and Moon brings a large visible area but no decrease in

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resolution. This peculiarity makes it possible to monitor a large scale geographical phenomenon subtly. In this paper, we discuss the system performance briefly at the beginning, and next analyze the baseline and potential application in global environment change study.

2. System Performance

The detailed system configuration is presented in reference [1] and [2]. For the convenience of analysis, the simplified observation geometry model of the moonborne SAR is assumed which ignores the moon orbiting motion effects on synthetic aperture. In this case the relative motion between antenna and ground targets is equivalent to a sliding spotlight mode. L-band provides a good compromise between the desire to drive the frequency down for a large range swath and high interferometric decorrelation and to increase the frequency for good resolution and inertia to interference, but the minimum antenna area and minimum average power are easier to implement when the system is operating at C-band and X-band. In addition, the instantaneous viewable area specified by incidence angle ranging from 10° to 70° , is about 40% of the entire Earth disc. The daily cumulative coverage is more than $2/3$ of the whole Earth surface, and an 8-hour tracking time per day is accessible for most targets in viewable area.

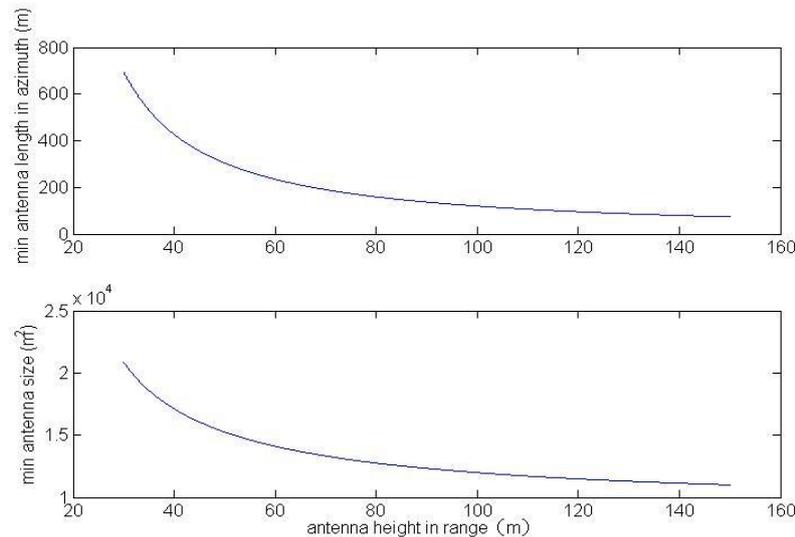


Figure1. The minimum antenna length and minimum antenna size as function of antenna height in range at L-band when the incident angle is 15° in near range.

The azimuth resolution ρ_a of moon based SAR can be approximated by

$$\rho_a = \frac{L_a}{2} \cdot \frac{R_e}{D_{em}} \cdot \frac{\cos \delta_g}{\cos \delta_m} \quad (1)$$

L_a , R_e , D_{em} , δ_g , δ_m stand for the antenna length in azimuth, Earth radius, the distance between Earth and Moon, latitude of target and declination of Moon, respectively. Because of the existence of the factor R_e/D_{em} derived from Earth curvature, the azimuth resolution is impressive high. Another bonus the curvature brings is the extension of range swath. For example, at L-band in standard mode (strip mode or more precisely the sliding spotlight mode) without ambiguity, a 2000km range swath and 4m azimuth resolution are achievable simultaneously by using a 70m antenna length in range. This contributes to both an integral coverage over large area and a detailed observation, which may promote the effectiveness of remote sensing data in regional and global environment study. ^[3]

Furthermore, a 6-beam scan SAR mode supports the entire coverage of the viewable area in both sides.

The minimum antenna size and power desire are two severe constraints which make the moon based SAR hard to realize in the near future without technique innovation. As the pulse repetition frequency must be higher than the Doppler bandwidth for sufficient azimuth sampling and lower than $2c/W_s$ to avoid the range ambiguities, there exists a lower bound of antenna size. c is the light speed and W_s stands for the slant range swath. Fig.1 shows the minimum antenna length and min antenna size as functions of antenna height in range at L-band when the incident angle is 15° in near range. Typically minimum antenna size would be 50% larger considering practical case, so the antenna for L band will not be smaller than 20000m^2 with a 70m antenna height. The case will be worse as the incident angle increases. But at C-band and X-band, the minimum antenna size is much smaller, and approximately decreases linearly with the wavelength.

3. Moonborne InSAR Baseline

The lunar base interferometric synthetic aperture radar (InSAR) can measure the earth dynamic in the line of sight with millimetric accuracy. It provides the potential to monitor the Earth plate motion and to predict the earthquake. In moonborne case, both repeat pass Interferometry and monorail double antenna interference mapping are feasible InSAR configurations.

With respect to existing SAR system, the main peculiarity of moon based SAR is related to the daily site accessibility which reduces the temporal decorrelation of repeat-pass interferometry.^[2] The critical baseline $B_{\perp c}$ leading to a complete spatial decorrelation is given by:

$$B_{\perp c} = \frac{B\lambda D_{em} \tan \theta_i}{c} \quad (2)$$

where B is the transmission bandwidth, λ is the wavelength, c is the light speed, and θ_i is the incidence angle equivalent to the difference between Moon's declination and the latitude of target. Fig.2 shows the critical baseline in different band with the incident angle ranging from 10° to 45° (the bandwidth is 100MHz). When the incident angle is 25° , the critical baselines are 14000, 3300, 1770 km at L-band, C-band and X-band respectively. The distance between adjacent passes $\Delta(\delta_m)$ which changes with the Moon's declination must be smaller than the critical baseline in order to implement the one day interval repeat-pass interferometry.

$$\Delta(\delta_m) \leq \frac{B\lambda \tan |\delta_g - \delta_m|}{c} \quad (3)$$

$\Delta(\delta_m)$ can be calculated by using the JPL ephemeris DE405. Its upper limit is about 33000 km. The boundary latitude of coverage area of one day repeat-pass interferometry is given by:

$$\delta_g \geq \delta_m - \arctan \frac{c\Delta(\delta_m)}{B\lambda} \quad \text{and} \quad \delta_g \leq \delta_m + \arctan \frac{c\Delta(\delta_m)}{B\lambda} \quad (4)$$

Consequently, regarding moonborne repeat pass interferometric system, L-band is the first choice by occasion of longer critical baseline and larger one day interval interferometric coverage area.

A more ambitious ideal is setting more than one antenna on Moon which offers the unique place for an orbital single pass system. In order to prevent the obstruction of looking view, antennas should be placed between 60°N and 60°S on Moon, and the maximum baseline is limited to 3000km. Table 1 shows an example of two antenna moonborne SAR system in which the antenna positions are related

to the critical distances. This configuration gains a stable and controllable baseline as well as higher costs. Compared with the L-band, C-band and X-band is more economical.

Table 1. An example of double-antenna moonborne SAR system (incident angle 15° as the worst case)

	L-band	C-band	X-band
Wavelength (cm)	24	5.6	3
Critical Baseline (km)	8100	1900	1000
Antenna position	60 N, 60 S	33 N, 33 S	16 N, 16 S

Even three dimension tomography is feasible on Moon with sufficient sampling. Other orbital satellite is inaccessible to acquire the multiview data simultaneously. However, the expansive lunar surface offers adequate space and stationary geometrical relationship for antenna queue, and the temporal decorrelation which precludes the 3-D imaging from earth orbit in forested area will be eliminated. An estimate of the reflectivity function with 3-dB elevation resolution ρ_s is related to the maximum orthogonal baseline extent S_T .

$$\rho_s = \frac{\lambda D_{em}}{2S_T} \quad (5)$$

The maximum orthogonal baseline of moonborne system is about 3000km, resulting in a 15m elevation resolution at L band, better than 26.6m given in [5].

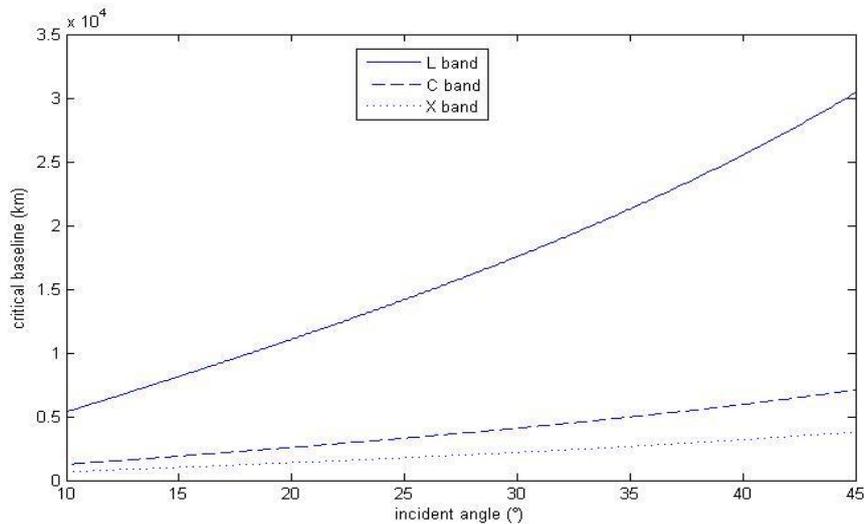


Figure 2. Critical baseline as a function of incident angle

4. Applications

InSAR is widely used in detecting the solid surface deformation caused by plane motion, volcano groundwater table depression and precipitation. Most lands on the Earth except the Antarctic continent could be observed by moonborne SAR 15 times per month (Table 2), which offers well temporal sampled data for earth dynamic study. Furthermore, the moon based InSAR is sensitive to the surface deformation along the longitude for its equivalent movement paralleled to the latitude, complementary to the low Earth orbit (LEO) InSAR systems which are sensitive to the east-west direction surface deformation.

Glaciers are sensitive factors of climate change. SAR offers the capability to image the changes in glacier area and to measure the flow speed. Particularly, the moon based SAR is of great potential in regional glacier research for its wide swath compared with the LEO SAR. Its mapping of polar region is disadvantaged by large incidence angle and insufficient sampling. However, at least the edge of polar ice sheet could be illuminated several times each month, so the interferometry with short temporal separation and the monthly time series interval are attainable in this area.

Table 2. Several observation parameters of moonborne SAR (28 days per month)

Latitude	Viewable times per month	Azimuth angle	Incident angle	Temporal coverage
Arctic Circle	11-15	135 °-225 °	43 °-60 °	39%-54%
40 °N	24-28	135 °-225 °	17 °-57 °	86%-100%
Tropic of Cancer	17-21	135 °-225 °	10 °-46 °	61%-75%
Equator	17-21	135 °-225 ° and 315 °-45 °	10 °-23 °	61%-75%
Tropic of Capricorn	17-21	315 °-45 °	10 °-46 °	61%-75%
40 °S	24-28	315 °-45 °	17 °-57 °	86%-100%
Antarctic Circle	11-15	315 °-45 °	43 °-60 °	39%-54%

Other applications include the disaster management, analysis of forest vertical attribute, topography^[1], land cover and land use change mapping and so on.

5. Conclusion

In this paper, the author has preliminarily analyzed a moonborne InSAR system with high spatial resolution, wide swath and good temporal frequency. This system is different from spaceborne InSAR for its imaging mode, coverage and viewing angle. It is useful in several fields, but in order to support the project more study on its potential applications is required.

Acknowledgement: Thanks for the support from National Natural Science Foundation of China (61132006, 41120114001) and The National Key Technology R&D Program (2012BAC16B01, 2012BAH27B05).

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