SYSTEM REQUIREMENTS AND MISSION ANALYSIS FOR SPACEBORNE SAR INTERFEROMETRY BASED ON FORMATION FLYING SATELLITES

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ABSTRACT:

With the purpose of further development of SAR satellite technique and for Earth's topography, SAR interferometry, with which one can get, not only images with target's azimuth and range information, elevation information, has come into application. Among these studies, formation flying satellites proposal is one of the most effective methods. This paper presents a brief introduction of the formation flying satellites system to support SAR interferometry. Besides the design of a single satellite, several new problems of the formation flying SAR satellites system should be solved, for instance, design of the formation configuration, determination and measuring method of the interferometric baseline, synchronization management of beams, frequency and time, and choice of working module, etc. System requirements and mission analysis during engineering realization are mainly discussed.

1. INTRODUCTION

Synthetic Aperture Radar (SAR) is a kind of active remote sensing techniques, with which high resolution 2D images can be obtained. Recent studies have demonstrated the usefulness of SAR interferometry for generation of target's elevation information using two (or more) SAR antennas. This geodetic technique is based on the combination of two SAR images of the same scene acquired from slightly different positions in space to measure a phase difference in each coregistered pixel. The measured interferometric phase can be used to derive topographic height information on the imaged terrain and thus to generate a Digital Elevation Model (DEM). By means of InSAR technique, accurate DEM and topographic mapping can be realized without limitation of weather or time, which indicates extensive and tremendous application prospects in fields of national economic construction, military and scientific research, etc. Moreover, ocean current, hypo information etc. can be explored by means of Along Track Interferometry (ATI). Terrain deformation measurement, base on Differential SAR Interferometry (D-InSAR), can be applied to the research of earthquake, volcano, glacier, surface settlement and landslide, etc.

Space-borne SAR interferometry takes the advantages in short-term and large-area acquisition of digital DEM, global coverage capability as well, and it is one of the symbols of synthetic national power. Formation flying small satellites operation mode, a kind of more effective method for longer baseline achievement of spatial SAR interferometry, processes creative work and takes tremendous latent application capability. This paper presents system configuration of formation flying small satellites, and analyzes the requirements for space-borne SAR Interferometry derived from the system.

2. SYSTEM CONFIGURATION

To gain the ends of measurement to the unknown region, "InSAR Satellite System" mainly consists of InSAR satellite (or satellites constellation), launch vehicle, launching site, TC&R web and on-ground application subsystem. InSAR satellite or satellites constellation mainly consist of the payload subsystem and the platform. On-ground application subsystem mainly consists of data preprocessing, on-orbit dynamic measurement, dedicate orbital determination and data processing subsystem, etc. Among them, interferometric SAR is applied to acquire data of the to be imagined target, and on-ground data processing subsystem preprocesses the transmitted data to achieve corresponding single-look complex imagine. After processing, DEMs and corresponding orthogonal images are obtained. From the viewpoint of SAR interferometry essential principles, it is still a kind of triangulation, and two SAR antennas are separated in the space to get the baseline, with which to form triangle with the target. When solving the relationship among the parameters within the triangle, the proceeding is from the range differences of the two SAR antennas, which depend on phase variation derived from different transmission patches of electromagnetic waves from the antennas to the same target. For the interest of requesting the phase difference, which can be utilized to achieve the elevation information, from two SAR complex images, it is commanded that these two images are coherent. Coherence is the premise for execution of SAR interferometry, and methods to obtain, maintain and increase coherence are basic and core topics for SAR interferometry imaging. Phase difference is very sensitive to the variation of distance (5mm/mrad) when the operation frequency is of microwave band (X-band 30mm), and InSAR data is from the same coordinate system, which supports compatible data accuracy. These characteristics of InSAR system lead to accuracy of meter-level DEM.

InSAR satellites constellation is composed of two or more satellites which are equipped with SAR systems and are separated some distance in the space for baseline formation. Effective baseline can be from several hectometers to several kilometers. Configuration of each satellite is of the same. Communication between satellites is achieved by interlink. Monostatic or bistatic mode can be adopted for receiving and transmission mode. The on orbit phase configuration is illustrated in Fig.1.

The on-ground application subsystem receives the downlink data of each satellite. Besides radar echoes needed for images, the received signals include data of orbit, attitude and baseline measurement information as well. With the assistance of dedicate orbital determination, the satellites can be accurate poisoned, and the mapping products are obtained after processing of interferometric SAR data, baseline measurement data and orbital data, etc.

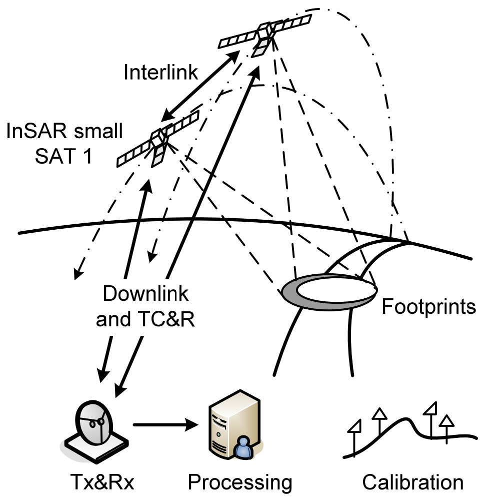

Fig.1 InSAR small satellites constellation on orbit phase configuration

2.1 On-board Operation Process

Operation process of the payload subsystem loaded on the satellite mainly takes transition and repetition actions among three kinds of states.

When the satellite arrives into its sun synchronous orbit, the SAR antenna comes into charging state by telecommand from the on-ground station. At the same time, small satellite steer its attitude to make the solar array panel towards the sun. In most cases, the satellite stays in this state. When charging is over, the radar is ready to come into operation. The information of time and regions to be imaged has been precalculated and modulated to the telecommand signals, which controls the satellite to steer attitude of itself or the SAR ntenna to point to the desired direction, then each satellite comes into operation state.

During radar imaging operation state, inter satellite synchronization is firstly initialized. The satellite which radiates electromagnetic waves towards the targets (main satellite) transmits synchronous signals by the wireless communication link. The passive satellite receives the synchronous signals and adapts its local oscillation and PRF. All these processes are completed in several seconds.

Data transmission equipments take the charge of store the compressed data and transmit them to the station. When the satellite is closed to the beam region of the ground station, telecommand makes the data transmission antenna on the satellite to point to the ground station, then the satellite comes into data transmission state. During this state, the satellite transmits the stored data in several minutes and then comes back into charging state.

Transition and repetition like charging, imaging, charging and transmission form the major operation process of the on board system.

Moreover, on-board InSAR system has the calibration operation state. Purpose of calibration is to detect system errors, which supply evidence for modification and compensation.

2.2 On-board System Configuration

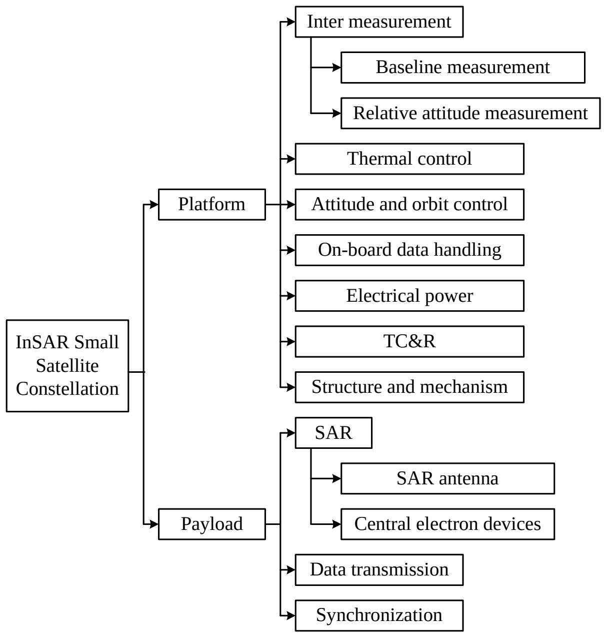

Fig.2 On-board system configuration

For Earth observation InSAR small satellites constellation, sun synchronous regression orbit with the height of around 500km, three-axis stabilization is usually chosen. When the satellite is in the sunlight area, the solar array supports the power needed, while during eclipse period, rechargeable battery. When the payload subsystem is on operation, the power is supported by both the solar array and rechargeable battery.

Platform of the common small satellite consists of structure and mechanism subsystem, thermal control subsystem, attitude and orbit control subsystem, unified propellant subsystem, electrical power subsystem, TC&R subsystem, on-board data handling subsystem, etc. While for SAR interferometry function, baseline measurement subsystem, relative attitude measurement subsystem, etc. should be loaded. Payload of InSAR small satellites constellation mainly consists of SAR antenna, central electron devices, data transmission subsystem and devices for inter synchronization. On-board system configuration is illustrated in Fig.2.

3. SYSTEM REQUIREMENTS ANALYSIS FOR SPACE-BORNE SAR INTERFEROMETRY

3.1 High Accuracy Baseline Measurement

According to further analysis to SAR interferometry theory, baseline error is the most sensitive element for absolute elevation reconstruction, while relative elevation accuracy is related to error of phase difference. Actually, error of phase difference depends on baseline decorrelation. For achievement of 5m absolute elevation accuracy, requirements to error of baseline length measurement should reach cm magnitude, while to baseline attitude angle, arc-second. There exists an optimum baseline to satisfy the requirements of elevation reconstruction accuracy and signal coherence. How to design and accurately measure the baseline parameters are important issues for the system to solve. During engineering practice, parameters should be paid attention to are baseline measurement accuracy and frequency. Present state measurement methods are GPS (GPS/GLONASS), radio, laser, infrared wave and visible light, etc. To apply them into baseline measurement of formation flying satellites, issues such as measurement accuracy, measurement data transfer rate, signal coverage zone and range, etc. should be considered. Performances of these measurement methods are compared in Table 1. For the baseline measurement of formation flying small satellites, to realize cm magnitude length error and arc-second angle error, it is impossible to only adapt radio, laser or infrared wave, and combination measurement method should be carried out. Furthermore, by utilizing the relationship among coordinate systems, single frequency GPS combined with differential measurement method or dual-frequency GPS can be adapted to achieve higher accuracy.

Besides baseline measurement accuracy, baseline measurement frequency should also be considered. Under the precondition of given satellite control accuracy, changing of baseline mainly depends on orbits difference and system disturbance. During satellite service life, it suffers from various kinds of disturbing forces from the space environment. The disturbing forces mainly include the additional gravity of the Earth's nonspherical shape and non-uniform mass, aerodynamic force of upper atmosphere, gravities from the sun and moon, and light pressure from the sun, etc. Under the effects of disturbing forces, periodicity, eccentricity radio, right angle of ascending node will change with time.

Method	Elements	Accuracy	Data trans-mission rate	Range	Coverage zone
Radio	Range Azimuth	cm 1 deg	High	>30km	Large region
	Relative position	Cm			
Laser	Range Azimuth	Mm 1e-4rad	low	>30km	Mrad~sub-mrad
Infrared	azimuth	Arc-second	low	>30km	Large region

Table 1 Comparison among different baseline measurement methods

3.2 Configuration of Formation Flying Satellites

As mentioned before, design of the configuration of formation flying small satellites should satisfy the command of baseline length and the restraint of elevation accuracy. Moreover, fuzzy elevation restraint condition should also be considered when designing the configuration. For the satellites operate on low earth orbits, the Earth gravity is the major acting force. Moreover, space environment, such as the Earth's nonspherical shape gravity field, atmospheric drag and light pressure from the sun, etc. makes the orbits changed. Design of the configuration should consider several factors, such as baseline length measurement, payload receiving and radiating signals, and fuel requirement for orbit maintaining, etc.

3.3 Receiving and Radiation Institution

At present, typical formation flying missions for SAR interferometry are Interferometric Cartwheel Plan, Interferometric Pendulum Plan, TerraSAR-X Tandem-X Plan and RadarSAT-2/3 Plan, etc. Receiving and radiation institutions of these plans take their own characteristic. So long as two radars take time sequence to radiate and receive signals, the institution can be divided into three modes, and they are pursuit monostatic mode, ping-pang monostatic mode and bistatic mode. Power requirement to the satellites will be decreased if equivalent operation modes are adopted.

3.4 Beam Synchronization

Issues of beam synchronization can be divided into two goals. One is to make the SAR antennas loaded on different satellites to point to the same target on the ground, and the other is to make the percentage of cross coverage zone of the two beams as high as possible. Beam control of the antennas can be achieved by steering attitude of the satellites or antennas themselves. Three-axis stabilized satellite could change its attitude by some driving moments. Although very little fuel is utilized for this action, a series of new problems rise and should be solved. For instance, control accuracy of the satellite is stricter; reliability of the satellite is worse, etc. There are two means for the antennas to achieve beam synchronization: mechanical movement and electric scanning. SAR antennas loaded on the satellites can make motions along their rolling axes and yawing axes, which make the beams point to different directions. But this method also decreases the system's reliability and time, amplitude information for rotation should be transmitted to the satellites in advance. Phase array antennas can overcome these problems. Moreover, through beam shape transition, input power requirement is reduced, which decreases the limitation for TWTA.

3.5 Time and Frequency Synchronization

Beam, time and frequency synchronizations are three synchronous issues for formation flying InSAR small satellites system. For the requirements of InSAR process to make long-term coherent accumulation in several minutes, request for these three synchronizations becomes harder. For the formation flying InSAR system, several SAR antennas are loaded on different small satellites, and because of fabrication errors and feeble environmental difference, frequency under-synchronization occurs consequentially. It is necessary to build up a mathematical model for description of elevation accuracy influenced by frequency under-synchronization, for example, transmitting the frequency error into fixed part changes with time and random part changes with system noise. Effects of elevation performance and resolution in either azimuth direction or range direction by these under-synchronizations should take into consideration. Frequency under-synchronization mainly introduces phase error. Analysis of time synchronization is some kinds of similar with that of frequency synchronization. Whatever methods taken for time and frequency synchronization, the final goal is to reduce the error introduced to interferometric phase, and to the formation flying InSAR small satellites system, phase synchronization is necessary.

4. SUMMARY

In China, three are several SAR small satellites are under development or to be investigated, and they are all to be launched in the next five to ten years for environmental and disaster monitoring. Two or more small satellites among them can be utilized to make up flying formation for SAR interferometry realization. This paper briefly analyzes the system requirements of this technique, and argumentation, system proposal, research and development of critical techniques are under process orderly. It is reliable that in the near future, technique of SAR interferometry derived from formation flying small satellites will substantially come into service; thereby requests for space-borne cartography can be satisfied with another effective method.