Chinese Surveying and Control Network for Earth-Orbit Satellites and Deep Space Detection

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ABSTRACT  The relationship between the surveying and control network (CSN) for earth-orbit satellite and spatial geodesy, and the relationship between the CSN for deep space celestial bodies and detectors, and deep space detection are briefly summarized, and so are the basic technical needs of the deep space surveying and control network (DSN). Then, the techniques, the constituents and the distributing of Chinese satellite CSN (CSCSN) and other radio observing establishments in China are introduced. Lastly, with the primary CSCSN and other observing establishments, some projects for China to rebuild a more perfect CSCSN, and to establish a DSN are analyzed and stated.

KEYWORDS  satellite surveying and control network; DSN; microwave radio radar; LLR; DSCCs; radio observation; space-based station

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Introduction

As to realize the project of spatial geodesy by geodetic satellites, it is necessary to establish a satellite controlling and surveying network (SCSN) to track, to survey, to remotely control and to communicate with earth-orbit satellite, for realizing the project of deep space detection, a deep space controlling and surveying network (DSN) should be established as well. That is to say, to set up a SCSN and DSN are the key task in China's spatial geodesy project and deep space detection project[1]. The basic establishments and technological demands of DSN have been introduced in Reference [2]. China has set up a network named Chinese satellite controlling and surveying network (CSCSN) for earth-orbiting satellite and spacecraft. Chinese Academy of Sciences (CAS) has also set up many radio observation establishments for radio astronomy. So it will be very important and valuable to organically combine all these establishments both of CSCSN and CAS, and to rebuild them to a more perfect CSCSN and a Chinese DSN. In this way, it will avoid to repeat construction, to save money and to improve the efficiency.

1 Chinese space controlling and surveying facilities

1.1 CSCSN

From 1960s, China has set up a controlling and surveying network for near-earth satellite, named CSCSN which began to operate for Dongfanghong-1' (the first satellite of China) launched in April 24, 1970. When China's Shenzhou-5 spacecraft carrying a person on board was launched successfully, the CSCSN...
has become the controlling and surveying network of Chinese spaceflight. In the CSCSN, the diameter of each antenna’s curved face is less than 20 m, therefore the network can only provide controlling and surveying service with high precise for the space detectors within the distance of 3.6 × 10^4 km from the earth, such as rockets, lower earth-orbit satellites, sun-synchronous satellites, geosynchronous satellites, airships carrying people and so on.

1.1.1 Construction of the CSCSN

The CSCSN is mainly composed of controlling and surveying stations and controlling and surveying centers. Chinese satellite controlling and surveying stations mainly include the fixed stations on the land and the mobile stations on the sea. The fixed stations on the land are divided into two parts. One part is in China and the other part is in other countries around the world. The fixed stations in China are respectively located in regions of Xiamen, Qingdao, Weinan (also named Xi’an station), Jiuquan, Neimenggu, Hetian and Kashi. They have almost covered the whole China. The fixed stations in other countries are respectively the Karachi station in Pakistan, Malindi station in Kenya and the Namibia station in Namibia. The mobile stations on the sea include mainly four “Yuanwang” ships to control and survey the spacecraft. For different track missions, the ships should be in different locations. As shown in Fig. 1 Chinese satellite control network, in the track of the flight of “Shenzhou-5”, the “Yuanwang-1” ship is located on the Pacific Ocean to the southeast Japanese sea, and the “Yuanwang-2” ship is located on Pacific Ocean to the eastern New Zealand, and the “Yuanwang-3” ship is located on the Atlantic Ocean to the western South Africa, and the “Yuanwang-4” ship is located on the Indian Ocean to the western Australia.

The controlling and surveying centers of the CSCSN are respectively located in Beijing, Xi’an and Jiuquan (Dongfeng command center), which send operating instructions, navigation instructions, tempering instructions and so on to the controlling and surveying stations, and to the satellites or airships.

1.1.2 Radio frequencies for control and survey

At present, CSCSN surveys and controls the flying targets in the ultra short wave; C wave band and S wave band.

1.1.3 Controlling and surveying equipment

The main controlling and surveying equipments of each controlling and surveying station include: the communicating system of satellite, which makes sure that the message can be transmitted between each controlling and surveying station and center; single impulse radar, which is used for catching and tracking the spacecrafts; the microwave uniform system for control and survey, which is the main controlling and surveying equipment working on the principle of response radar. Spacecraft receive the microwave signal sent out by the microwave uniform system and later send out the answering signal. The transmission of digital signal of remote surveying, remote controlling and communication is completely executed on it. In this way, it has formed a bidirectional expedite message loop among the command centers, the controlling and surveying ships and the spacecrafts.

1.1.4 Observation techniques adopted by the controlling and surveying stations

Radio interferometry: to survey the angle of the spacecraft by comparing the received phases.

Dual frequencies Doppler: to survey the speed of the spacecrafts.

Microwave radar surveying: to survey the distance from the ground station to the spacecrafts.
and get the images of the spacecrafts.

1.2 Equipments of the radio observations of China

CAS has respectively set up two radio telescopes with the diameter of 25 m at Shanghai Astronomical Observatory in 1987 and at Urumchi Astronomical Observatory in 1993. The two radio telescopes have formed the fixed VLBI observation stations of China. And the mobile VLBI station developed by Xi’an Surveying and Mapping Institute and Shanghai Astronomical Observatory is parked in Kunming, which has formed the VLBI observation network of China with the two fixed VLBI observation stations above.

In 1984, the Beijing Astronomical Observatory had set up a metric wave synthetical aperture composed of 28 radio antennas with each a diameter of 9 m. And the Purple Mountain Observatory has installed a millimeter wave radio telescope with a diameter of 13.7 m in Delingha of Qinghai Province in 1990. With the coming of the 21 century, the development of radio astronomy requires bigger antennas to receive radio signals. And the international radio astronomy group has advised to set up a huge telescope (square kilometer area, SKA) with a receiving area of 1 km². To realize the SKA plan, Chinese astronomers have tabled a proposal to use the karst depressions in Pingtang and Puding counties of Guizhou Province, and to establish the telescope arrays of about 30 individual unit telescopes with each roughly 200 m in diameter to implement the 1 km² receiving area. A five hundred meter aperture spherical telescope (FAST) proposed to be built is the forerunner project of the SKA plan.

2 Construction project of the Chinese DSN

2.1 Reconstruction of the CSCSN

The earth is approximately a elliptical sphere with a major radius of about 6 378 140 m and a flat rate of about 1/298.257. Therefore one cir-
both from the Xiamen station and the Namibia station. In the Antarctica, to set up a Antarctica station which is about 7,000 km away both from the Australian station and South America station. In this way, the CSCSN has become a new network which cover the whole world and is able to continuously track and observe the satellites and spacecrafts.

When China cannot set up any fixed stations in some places for political reasons or diplomatic reasons, the spaceflight surveying and controlling ships can be berthed on the high seas near the planned fixed stations to ensure that the spaceflights can continuously be tracked. Of course, the limit of the stability of the ships will affect the precision and efficiency of survey. If the situation is allowable, we can raise the precision and efficiency by applying the surveying and controlling stations established in the countries or regions near our planned places.

![Fig. 2 Plan of Chinese satellite control network](image)

![Fig. 3 Space visibility of Chinese satellite control network](image)

2.2 Establishing the DSCCs

At present, the diameters of the radio antennas in the CSCSN are all equal to or less than 20 m, which can only observe the near-earth satellites and spacecrafts no more than $3.6 \times 10^4$ km from the earth. So our country need to add some radio antennas with different diameters, such as 25 m, 35 m and about 70 m, which will form a group continuously tracking, surveying and communicating with the earth-orbit satellites and spacecrafts and detectors of the solar system. This group is called a deep space communication complex (DSCC).

The celestial bodies in deep space are a great distance away from the earth. The moon which is the nearest celestial body of the earth is averagely 384,400 km away from the earth. Because of the earth rotation and the relative movement between the earth and the celestial bodies, and between the spacecrafts and the earth, a station on the ground can only track a spacecraft for a voyage of 19,800 km once (the ground distance of the spacecraft flying around the earth is 40,000 km). So, for having ability to continuously observe the celestial bodies in deep space and spacecraft, at least three DSCCs covering the earth are needed in Chinese DSN, which provides a close control for some regions where the received signals can overlap when the detector is flying from one DSCC to another, and where the interferometry can be carried out.

When the DSN tracks and observes the detectors or the celestial bodies, it is mainly the rotation of the earth that interrupts the continuous observation of a DSCC. So at least three DSCCs are needed, which are respectively about 120° apart away along the longitude. To make sure that each DSCC can possess a continuous observation time of 8 to 14 hours, the DSCCs should be located near the equator. The first DSCC can be selected round the Xiamen station in the CSCSN, and the second DSCC can be selected round the Namibia station of the CSCSN, which is located in Africa mainland of the south hemisphere. And the third DSCC can be selected round the North America station of the CSCSN. Selecting stations of the Chinese DSN in this way can ensure the station interval is about 120° along the longitude and cover the southern and
northern Hemisphere. With each of the DSN station as a center, a circle with 19 000 kilometer observation diameter is drawn on each station. And each circle expresses the observation area. Projected on the plane, the stations and circles are shown in Fig. 4, where the observation areas have almost covered the whole earth. The area A and the area B in the Fig. 4 represent the uncovered regions. The ground distance between every two neighboring DSCCs is about 12 000 km. In the overlap regions of the received signals, the resolution of the observation angle can reach 1.29 mas (for radio wave of 7.5 cm wavelength in the S wave band).

To establish the Chinese DSN, it is very important to investigate the locations, category and function of the observation equipments of the CAS and of the CSCSN. And then the 25 m, 35 m and 75 m radio antennas should be constructed additionally to form a domestic DSCC, avoiding the repetition of construction.

On the Namibia station and North America station, on the one hand, it is necessary to construct the antennas of different diameters to form a DSCC. On the other hand, the surveying and controlling equipments established by other countries can be used as the parts of the DSCC in the Chinese DSN, by which the charge will be saved and the structure of the DSCCs is strengthened and the tracking covering area on the earth is enlarged. Such controlling equipments established by other countries are as the European VLBI network (EVN), the U.S. very long baseline array (VLBA) and DSN of NASA, the networks in the Russia and in Japan, networks in the southern Hemisphere (e.g., the Australia telescope (AT) and Australian VLBI antennas), networks in Asia (e.g., India) and in Canada.

2.3 Deep space radar observation system of China

At present, the CSCSN has adopted the microwave radar system to observe the distance between the ground station and the lower earth-orbit satellites or spacecrafts and image them. But the distance between the earth and the celestial bodies in the deep space such as the planets and the distance between the earth and detectors are very far. The echo received by the radar is very faint. Adopting synthetic aperture radar formed with multi-radar receiving to proceed interferometry will add the synthetical antenna’s diameter, increase the energy of the receiving signal and the observing resolution and the imaging quality of radio objects, and the effective receiving region of the echo by radar on the ground is in a area of several hundred kilometers. The further distance between the center and the echo is, the more faint the received signal will be. Thus the length of the interferential baseline on the ground and the synthetic aperture are limited. Therefore, using the higher frequency of radar wave is more feasible to increase the observing resolution of the deep space celestial bodies and imaging quality.

The electromagnetic wave that can traverse the atmosphere and arrive on the ground is divided into several frequency bands.

At present, the international deep space radar system has used the X band which is 3-4 times higher than the S band used by the CSCSN, and the resolution of radar increases by the same times. The international deep space radar system has already received the echoes from some planets (Mercury, Venus, Mars, Jupiter and the satellite of Saturn, moon, asteroid, comet and so on of solar system).

Some scientific research institutions in China have begun to approve that the X bands microwave radar can be used in altimetry, and they are researching the collectivity design of the altimetry microwave radar. So we have the basis
to increase the frequency of radar system to X band in the CSCSN.

The power of the radar wave transmitted by the radar subsystem should be above 500 kW, and the radar subsystem need to convert the alternating current into the powerful X band microwave transmitted to the deep space target. And there is also needs to develop the technology of low noise amplifiers to improve the quality of the received echoes. Adopting the antenna with 70 m diameter can realize the receipt of radar signal by a single antenna, and to associate the antenna with 70 m diameter with the other surveying and controlling stations with antennas of 35 m and 25 m diameter to form a synthetic aperture radar and to improve the resolution and imaging quality.

According to the request of the precision of the surface manufacture of the radio telescope antenna, whose rms should be equal to or less than $\lambda/20$ ($\lambda$ is the wavelength of the observed radio). So, when the wavelength of the X band is 3.75 cm, the precision of the manufacture of the radio antenna’s surface should be high, and its rms $\leq 0.19$ cm.

2.4 Building the lunar laser ranging system of China

From America’s starting up the Apollo moon project in 1961, three laser reflectors which are respectively named Apollo11, Apollo14 and Apollo15 have been installed on the moon. And the former Soviet Union has also installed two reflectors named $L_1$ and $L_2$ by the unpiloted spacecrafts. All of these reflectors have provided the targets for lunar laser ranging (LLR).

At present, the international LLR stations on the ground have adopted the laser wave with very narrow beam and with 0.1 ns lasting time of the pulse, and the precision of LLR can reach 0.03 m.

At present, China has set up several satellite laser ranging (SLR) stations which is necessary to be developed to LLR stations which is useful for surveying the distance between the ground station of China and lunar laser reflectors with high precision, and which will have important meaning for lunar detection and deep space detection: (1) adopting the technology of LLR can determine the lunar moving orbit with high precision and can also improve the lunar calendar which is the necessary condition to precisely design the flying orbit of the lunar detectors. (2) using the laser observing stations with the known coordinates, we can resect the coordinates of each reflector and precisely survey the lunar rotation and the lunar librations, which can provide good conditions for research of lunar dynamics, and to set up lunar coordinate system and to connect the lunar coordinate system with earth coordinate system. It has the important significance for China to digitize the lunar, to realize the lunar detection and to construct the lunar testing base and so on.

2.5 Setting up the space based CSCSN

In CSCSN, because of the diameter limit of the earth, the resolution of angle is restricted for the observation with VLBI. Because of the influence of aerosphere, the frequency of radio observation should be within the band of the atmospheric window. Therefore, it is necessary for China to launch an earth-orbit satellite with a radio telescope which can be associated with the radio telescopes on the ground to carry out interferometry. The ground telescopes and the space telescopes have formed the space VLBI and have developed the space based surveying and controlling network. In this way, the length of interferential baseline of the space VLBI break through the restriction of earth diameter, and also the resolution of the observation angle break through the limit of the ground VLBI.

The time delays and time delay rates of the same radio signals received by the space VLBI antenna and the ground VLBI antenna are concerned with three reference systems, the first of which is the radio celestial conventional inertial reference system (CIS) defined by the radio source, the second of which is the dynamic inertial reference system defined by the satellite motion, and the third of which is the conventional
establish the space based surveying and controlling network.

3 Conclusions

1) There is need to additionally establish ground surveying and controlling stations in CSCSN and to research their distribution for the CSCSN to precisely and continuously track the satellites in different near-earth orbits. This paper puts forward some suggestions and plans for this.

2) It needs to rebuild the CSCSN to the DSN and also to construct DSCCs to synthetically serve for tracking, surveying, navigation and communication with various detectors.

3) Developing Chinese LLR will set up the base to precisely determine the lunar orbit, to establish and precisely survey the control network on the lunar surface, to study the lunar dynamics and lunar rotation and to carry out selendesy.

4) Constructing the deep space radar system of China will set up the base for carrying out the initiative observation of the near-earth planets to offset the incapacity of the ground laser survey which cannot survey the planets, and for getting the radar images of the planets and analyzing their material distribution. And it is also very important for planet ranging, determining their orbits and positions. And it will set up the base for designing the orbits of planet detectors, for planet geodesy and for the deep space geodesy.

5) The set up space based surveying and controlling network can directly connect the CTS, the dynamic inertial system and the CIS which are concerned with the deep space detectors and the deep space geodesy. In addition, the space based surveying and controlling network can avoid the system error by adopting different technologies to indirectly connect the reference systems. And the precision of surveying, connecting and maintaining the reference systems is improved.

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