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Active surface control for a large radio telescope

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Abstract: Due to gravity, temperature, humidity, wind loading, etc, there are errors between the actual surface and the ideal surface of a radio telescope antenna when it is at work. To compensate for these errors and improve the global performance of a large radio telescope such as Delingha 13.7 m millimeter-wave telescope, a novel active surface control method was proposed to increase its resolution, sensitivity and observation efficiency at high frequencies according to the changes of its antenna situation in the observation process. A controller area network/ethernet protocol converter was designed for the communication between the active surface control computer as a host computer in ethernet and the displacement actuator controller in controller area network. The closed-loop control of the displacement actuator driven by a stepper motor and controlled by an intelligent controller improves the control accuracy greatly through the feedback link based on the optical encoder.

Key words: 13.7 m millimeter-wave telescope; active surface; displacement actuator; controller area network/ethernet protocol converter; closed-loop control

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大型射电望远镜主动反射面控制

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摘要：针对13.7 m毫米波望远镜的特点提出一种新型主动反射面的控制方法，消除重力、温度、湿度和风力等对主反射面的影响，从而提高大型射电望远镜的分辨率、灵敏度和观测效率，设计了一种CAN/ethernet协议转换器，实现CAN中大量位移促动器与其在工业以太网中的主机的通信，通过光电编码器的反馈闭环控制位移促动器的驱动电机，大大提高了反射面的控制精度.

关键词：13.7 m毫米波射电望远镜；主动反射面；位移促动器；CAN/ethernet协议转换器；闭环控制

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0 Introduction

Active optics is a technology used with reflecting telescopes developed in the 1980s, which actively shapes a telescope's mirrors to prevent deformation due to external influences such as wind, temperature, humidity, mechanical stress and so on. Active optics could be divided into two types: the thin-mirror active optics and the segmented-mirror active optics. Active optics improves image quality, reduces cost and makes it possible to build a very large telescope[1-2].

To collect more radio signal and increase resolution and sensitivity, researchers have expended tremendous efforts in recent years to increase the size of the radio antenna together with building a radio antenna array. The active optics applied in radio telescope makes it much easier to get a larger single aperture and shorter observing wave length. Radio telescope usually has a very large diameter with its antenna consisting of a great number of small regular panels. Traditional radio telescope usually adopts passive antenna. Before or between the operations, the antenna is tested and adjusted at an intermediate elevation of its operation sky area and will not be actively aligned during running.

Below is the preliminary configuration for the primary reflector. As shown in Fig. 1, the segmentation layout for the telescope primary reflector of Delingha 13.7 m millimeter-wave telescope from Purple Mountain Observation China has 2 rings of keystone panels. The inner ring is made up of 24 identical panels while the outer ring of 48, a total of 72 panels fixed on the back structure through 216 mount points. The relative position of mount points is changed by the deformation of the back structure due to gravity, temperature, etc., resulting in the deformation of each panel besides its own[3].

As we know, the radio telescope will suffer the influence of gravitational deformation, wind load, etc. and its parabolic global antenna figure should be maintained within the tolerance range as frequently as it can. Large (more than 10 m in diameter or length) radio telescopes always bend during operation, due to their enormous weight, environment temperature, etc. and the fact that even the strongest materials are not perfectly stiff. This bending, typically in the range of a few millimeters, does not affect low frequency operation much, but dramatically reduces the efficiency of the telescope such as the millimeter/sub-millimeter telescope at higher frequencies where the wavelengths are comparable to the distortion. (Typically, the efficiency of a telescope drops appreciably when the deviation from the desired shape is more than 1/10 of the considered wavelength).

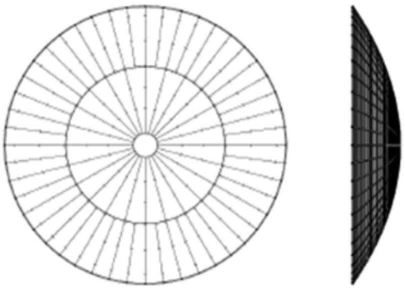

Fig. 1 Layout of primary reflector

An active surface is a surface of a radio telescope that is under the active computer control of its shape. For a radio telescope's antenna with panels, these panels are installed and adjusted to be a continuous surface at the corners, where there is a conjunct displacement actuator supporting the several neighboring panels. Besides the design of an improved and stiff enough antenna mechanical support, an active surface, as key techniques for constructing a large radio telescope, is now developed to solve the above problem, using numerous small actuators to move the surface panels with respect to the underlying frame, thus maintaining the correct shape, like the segmented mirror active optics widely applied in optical/infrared segmented primary reflecting telescopes[4].

An active surface can try to compensate for many different types of errors. The first is gravity — this is simplest since previous measurements, or even a mathematical model, can be used to predict (and correct) any bending. More difficult is the correction for wind and thermal errors, since these errors require measuring and correcting in real time. Therefore, a real time system should be developed to implement the active surface control and estimate the real time figure at any elevation angle, which would real time test all the surface deflection of all panels of the whole antenna, thus real time aligning them through actuators' adjustment.

In this paper, the preliminary work of the accuracy-upgrading task is introduced for the above 13.7 m millimeter-wave telescope. A Shack-Hartmann device is proposed to measure and maintain the curvature of the active surface and co-focus, together with a set of displacement sensors at the edge of each panel to maintain co-phase of the active surface. Compared with the optical telescope, there is something still different for Shack-Hartmann wave front measuring, because the working wavelength is much longer than that of visible light, and it should be used in daytime without stellar sources for wave front sensing. For the displacement sensor, since it only needs accuracy in micron meters, which is about a hundred times lower than that of the optical telescope, a kind of displacement sensor with micron meter accuracy such as Linear Variable Differential Transformer (LVDT) should be good enough and inexpensive. The following is the scheme of reflector adjustment system for the above 13.7 m millimeter telescope.

1 Scheme of reflector adjustment system

Due to gravity, temperature, wind, etc., there are errors between the actual surface and the ideal surface of the antenna consisting of panels when a large radio telescope is at work. To compensate for these errors, the reflector adjustment system is introduced to improve the observation efficiency of the antenna at high frequencies according to the changes of the antenna situation in the observation process through the communication between the active surface control computer and intelligent controllers based on controller area network as shown in Fig. 2. The active surface control computer estimates the real time active surface figure at any elevation angle and sends the compensations to the intelligent controllers to reduce or eliminate the adverse effects of the reflector deformation. The intelligent controller issues action orders to the displacement actuators to adjust the real-time position of the antenna panels for the required antenna reflector accuracy. At the same time, the intelligent controllers report the current situation of the actuators to the active surface control computer to monitor the real-time status of each control node.

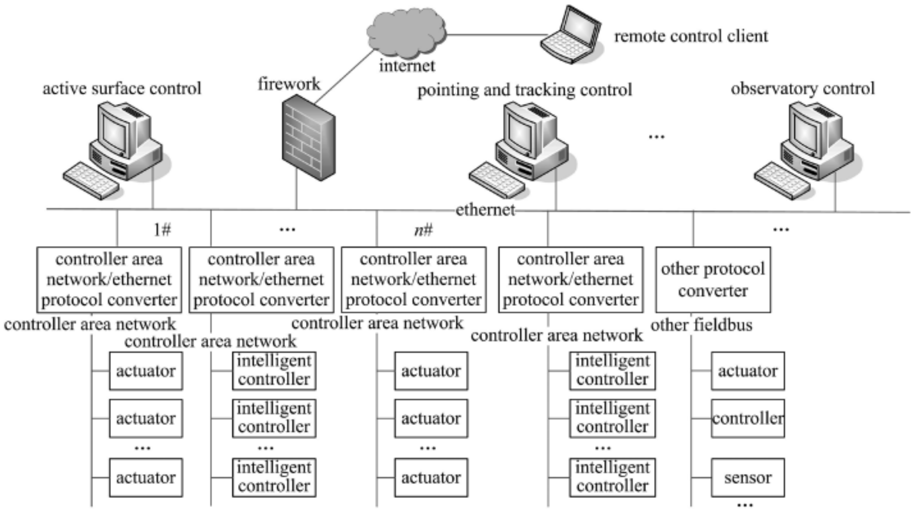

Fig. 2 The scheme of a reflector adjustment system for the above 13.7 m millimeter telescope

2　Calculation of displacement

A displacement actuator is placed at the common point of per four panels. There are N sets of displacement actuator. x_i is the displacement of the i actuator, s_{i0} is the acquisition value of coplanar calibration, s_{ij} is the feedback value of real-time control at j moment, so

$$S_0 = \begin{bmatrix} s_{10} \\ s_{20} \\ \cdots \\ s_{n0} \end{bmatrix},\ S_j = \begin{bmatrix} s_{1j} \\ s_{2j} \\ \cdots \\ s_{nj} \end{bmatrix},\ Y = S_0 - S_j$$

and

$$a_{ij} = \frac{\partial s_{ij}}{\partial x_i}$$

Then the control equation is

$$\left.\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1i}x_i + \cdots + a_{1n}x_n = y_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2i}x_i + \cdots + a_{2n}x_n = y_2 \\ \cdots \\ a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{ni}x_i + \cdots + a_{nn}x_n = y_n \end{array}\right\} \tag{1}$$

Written in matrix form as

$$\boldsymbol{A}\vec{\boldsymbol{X}} = -\vec{\boldsymbol{Y}} \tag{2}$$

$\boldsymbol{A} = \begin{bmatrix} a_{11}, a_{12}, a_{13}, \cdots a_{1m} \\ a_{21}, a_{22}, a_{23}, \cdots a_{2m} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ a_{n1}, a_{n2}, a_{n3}, \cdots a_{nm} \end{bmatrix}$ is the actuator influence function, $N=486$.

Using the least squares method, there is

$$\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A}\vec{\boldsymbol{X}} = -\boldsymbol{A}^{\mathrm{T}}\vec{\boldsymbol{Y}} \tag{3}$$

According to the above equation, write a program run in the active surface control computer to solve the actuator displacement $\boldsymbol{X}$ with Gaussian elimination method, and then convert it into the steps of the stepper motor to achieve automatic control of the displacement actuator. A controller area network/ethernet protocol converter is designed below for the communication between the active surface control computer as a host computer in ethernet and the displacement actuator controller in controller area network[5].

3　Controller area network/ethernet protocol converter design

The protocol conversion hardware and software structure is shown in Figs. 3 and 4

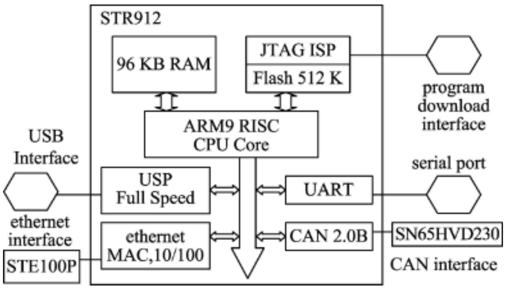

Fig. 3　Hardware structure of protocols converter

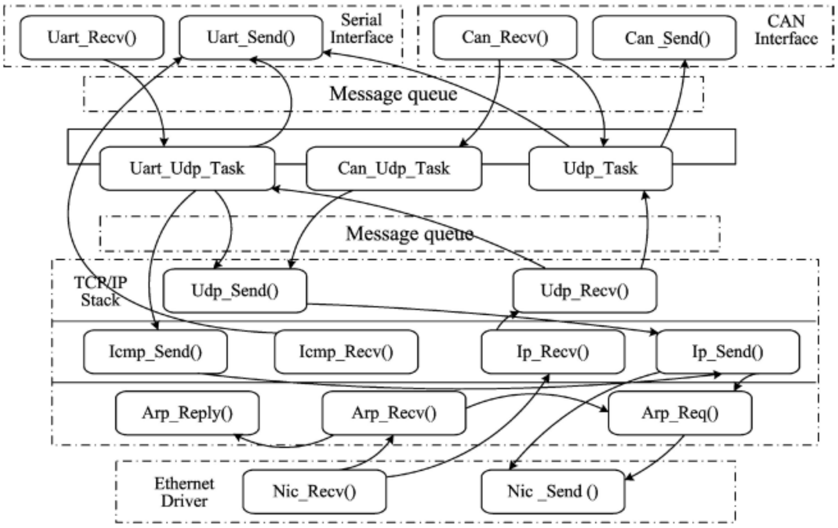

Fig. 4　Software structure of protocols conversion

respectively. TCP/IP protocol stack is implemented by TcpIp_Task. Data receiving of CAN is triggered by interruption. In the interruption service program, messages are sent to Can_Task and Can_Recv( ) is called to judge the data type. Messages are sent to drive Udp-Task if it is a query message and to drive Can_Udp_Task if it is an alarming message.

4 Actuator and its intelligent controler

The displacement actuator controller in controller area network receives the displacement estimation from the active surface control computer in ethernet through the above protocol converter. As shown in Fig. 5, the entire closed-up control system of the displacement actuator includes a driver, an intelligent controller and a feedback link based on the optical encoder. Integrating the controller and driver achieves the closed-loop control of the stepper motor and improves the control accuracy greatly[6].

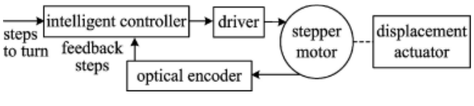

Fig. 5 Closed-loop control of displacement actuator

The optical encoder built in a stepper motor detects the rotation angle of the stepper motor to make the driver with out-of-step detection and stall protection function. The intelligent controller receives instructions from the active surface computer and judges and regulate step losses.

5 Conclusion

To collect more radio signals and increase the resolution and sensitivity of a radio telescope, researchers have expended tremendous efforts in recent years to increase the size of radio antenna together with building a radio antenna array. A radio telescope usually has a very large diameter with its antenna consisting of a great number of small regular panels. A traditional radio telescope usually adopts a passive antenna. Before or between the operations, the antenna is tested and adjusted at an intermediate elevation of its operation sky area and will not be actively aligned during running. However, due to gravity, temperature, humidity, wind loading and so on, there are errors between the actual surface and the ideal surface of the antenna when a large radio telescope is at work. In this paper, the outline of the active surface technique of a large radio telescope is analyzed to increase its resolution and sensitivity. Then, considering the characteristics of the primary reflector of a 13.7 m millimeter-wave telescope, a novel active surface control method is proposed to compensate for the above errors and improve the observation efficiency of the antenna at high frequencies according to the changes of the antenna situation in the observation process. A controller area network/ethernet protocol converter is designed for the communication between the active surface control computer as a host computer in ethernet and the displacement actuator controller in controller area network. The displacement actuator is driven by a stepper motor and controlled by an intelligent controller with the data from the active surface computer. The closed-loop control of the stepper motor improves the control accuracy greatly through the feedback link based on the optical encoder.

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