A Reconstruction Method of Large Shaped Reflective Surface Antenna Based on Zernike Polynomials and Least Squares Method

Congsi Wang[1,2,3], Hao Wang[1], Haihua Li[1], Kang Ying[1], Wei Gao[2], Qian Xu[4], Binbin Xiang[4], Zhihai Wang[5], Chao Jiang[6], Meng Wang[7]

1. Key Laboratory of Electronic Equipment Structure Design, Ministry of Education, Xidian University, Xi'an 710071, China

2. School of Civil and Environmental Engineering, University of New South Wales, Sydney 2052, Australia

3. Department of Mechanical Engineering, University of California, Berkeley, CA 94720, USA

4. Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi 830011, China

5. CETC No.38 Research Institute, Hefei 230088, China

6. State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, College of Mechanical and Vehicle Engineering, Hunan University, Changsha 410082, China

7. Research Institute of Shaanxi Huanghe Group Co., Ltd., Xi'an 710043, China

*Corresponding Email: congsiwang@163.com, 907646210@qq.com

The shaped reflector antenna enhances the effective radiation of the target area by optimizing the shape of the reflector surface so as to meet the requirements for the complicated working environment and diversified operating modes. And it's significant precondition and foundation of the compensation and the precise switching of the surface shape for the large active reflector antenna active surface to ensure the accurate reconstruction. In view of the long reconstruction cycle disadvantages of the traditional optimization algorithms (such as genetic algorithm), Zernike polynomials based on orthogonal basis functions combined with least squares method is used in this paper to get trigonometric coefficients of the reconstruction equations. Besides, comparing with the optimization algorithm we have proved the correctness and accuracy of the algorithm. Numerical results show reflective surface accuracy of 0.042968 mm by using this method to reconstruct the main reflect surface of the 110-meter aperture antenna to provide the necessary global antenna reflector precision information for switching and performance compensation in different frequency bands.

Shaped reflector antenna surface reconstruction equations can be expressed by Zernike polynomials as:

$$z(\rho,\theta)=\sum_{n=0}^{N}\sum_{m=0}^{M}\left[C_{mn}\cos(m\theta)+D_{mn}\sin(m\theta)\right]R_n^m(\rho) \quad (5)$$

The exact form of Zernike polynomials of the reflector surface is determined by the projection azimuth and radial index schemes (N, M). Written coefficients equations as a matrix form $A*X=\beta$:

Where,

$$A=\begin{bmatrix} Q & \sum_{i=1}^{Q}(\rho_i\cos\theta_i) & \sum_{i=1}^{Q}(\rho_i\sin\theta_i) & \sum_{i=1}^{Q}(2\rho_i^2-1) & \cdots & \sum_{i=1}^{Q}R_M^N(\rho_i) \\ \sum_{i=1}^{Q}(\rho_i\cos\theta_i) & \sum_{i=1}^{Q}(\rho_i\cos\theta_i)^2 & \sum_{i=1}^{Q}(\rho_i\sin\theta_i)(\rho_i\cos\theta_i) & \sum_{i=1}^{Q}(2\rho_i^2-1)(\rho_i\cos\theta_i) & \cdots & \sum_{i=1}^{Q}R_M^N(\rho_i)(\rho_i\cos\theta_i) \\ \sum_{i=1}^{Q}(\rho_i\sin\theta_i) & \sum_{i=1}^{Q}(\rho_i\cos\theta_i)(\rho_i\sin\theta_i) & \sum_{i=1}^{Q}(\rho_i\sin\theta_i)^2 & \sum_{i=1}^{Q}(2\rho_i^2-1)(\rho_i\sin\theta_i) & \cdots & \sum_{i=1}^{Q}R_M^N(\rho_i)(\rho_i\sin\theta_i) \\ \sum_{i=1}^{Q}(2\rho_i^2-1) & \sum_{i=1}^{Q}(\rho_i\cos\theta_i)(2\rho_i^2-1) & \sum_{i=1}^{Q}(\rho_i\sin\theta_i)(2\rho_i^2-1) & \sum_{i=1}^{Q}(2\rho_i^2-1)^2 & \cdots & \sum_{i=1}^{Q}R_M^N(\rho_i)(2\rho_i^2-1) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \sum_{i=1}^{Q}R_M^N(\rho_i) & \sum_{i=1}^{Q}(\rho_i\cos\theta_i)R_M^N(\rho_i) & \sum_{i=1}^{Q}(\rho_i\sin\theta_i)R_M^N(\rho_i) & \sum_{i=1}^{Q}(2\rho_i^2-1)R_M^N(\rho_i) & \cdots & \sum_{i=1}^{Q}R_M^N(\rho_i)^2 \end{bmatrix} \quad (10)$$

$$X=\begin{bmatrix}C_{00} & C_{11} & D_{11} & C_{02} & \cdots & D_{MN}\end{bmatrix}^T \quad (11)$$

$$\beta=\begin{bmatrix}\sum_{i=1}^{Q}z_i & \sum_{i=1}^{Q}(\rho_i\cos\theta_i z_i) & \sum_{i=1}^{Q}(\rho_i\sin\theta_i z_i) & \sum_{i=1}^{Q}(2\rho_i^2-1)z_i & \cdots & \sum_{i=1}^{Q}R_M^N(\rho_i)z_i\end{bmatrix}^T \quad (12)$$

Table 4 Coefficients by LMS and optimization algorithms(N=4,M=4)

Coefficients	**LMS**	**optimization algorithms**	**Coefficients**	**LMS**	**optimization algorithms**
C_{00}	10.415743	10.415743	C_{33}	-0.001178	-0.001178
C_{11}	-0.002948	-0.002949	D_{33}	-0.000095	-0.000152
D_{11}	-0.000092	-0.000117	C_{04}	-0.000381	-0.000381
C_{02}	10.415106	10.415107	C_{24}	0.000473	0.000473
C_{22}	0.002452	0.002453	D_{24}	-0.000030	0.000518
D_{22}	0.000197	0.000311	C_{44}	0.000318	0.000318
C_{13}	-0.001510	-0.001511	D_{44}	0.000043	0.000071
D_{13}	-0.000020	-0.000235	**Accuracy**	0.042968*mm*	0.044671*mm*

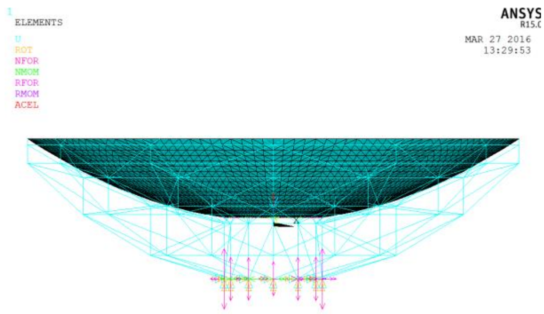


Fig.2 110-meter aperture antenna ANSYS model

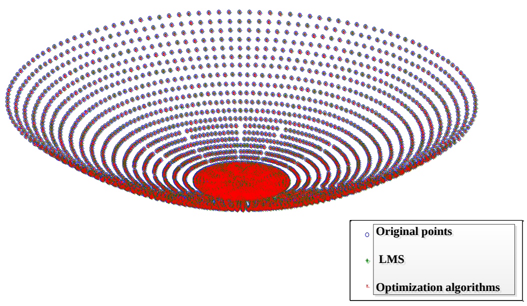


Fig.2 Discrete points expressed by LMS& optimization

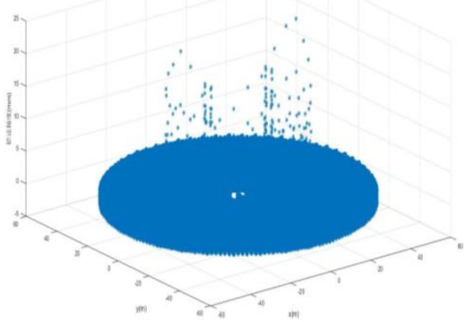
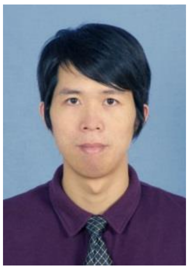


Fig.3 Error distributions between LMS& optimization



Congsi Wang received the B.S., M.S. and Ph.D. degrees in Electromechanical Engineering from Xidian University, Xi'an, China, in 2001, 2004 and 2007, respectively. Dr. Wang is currently a Professor of Electromechanical Engineering in the Key Laboratory of Electronic Equipment Structure of Ministry of Education, and Vice Director of Institute of Mechatronics, at Xidian University. From 2009 to 2011, he served as a Postdoctoral Fellow at Nanjing Research Institute of Electronics Technology (NRIET), Nanjing, China. From 2012 to 2013, he is a Visiting Scholar at University of California, Berkeley, USA.

His research interests are primarily in the area of Electromechanical Coupling of Electronic Equipments with emphasis on the modeling, influencing mechanism, design and application of structural-electromagnetic-thermal coupling of antennas including phased array antennas, reflector antennas, deployable antennas and so on. He has published authored or co-authored over 80 technical papers and one book, and holds 18 licensed China patents and 19 registered software copyrights. He received many awards including the 2013 and 2008 State Science and Technology Progress Award (Second Class), the 2014 Shaanxi Province Science and Technology Award (First Class), and the 2011 Outstanding Team Award for National Science and Technology Plan Execution, and the 2012 Technological Invention Award of High Education (Second Class), Ministry of Education of China. He was also the recipient of the 2015 National Natural Science Foundation for Excellent Young Scholars of China, the 2014 Young Scientists Award of International Union of Radio Science (URSI), the 2009 New Century Excellent Talents in University of Ministry of Education of China, and the 2011 Second Xi'an Youth Science and Technology Talents Award given by the Xi'an Municipal Government.