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# Research on position error of sparse optical system

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ABSTRACT

The main method to improve the resolution of optical system is to increase the aperture of the optical system, and it is a common method to use the sparse-aperture mirrors to obtain a large aperture primary mirror. The primary mirror of optical system is deployed when it is launched into the orbit, and the deviation between deployed position and design position determines the quality of the optical system. So it is necessary to analyze the position accuracy of segmented mirrors. Sparse-aperture optical system is modeled by optical software Zemax, and by adjusting six degrees of freedom of segmented mirrors can get curves between position error and image quality. The results show that different positions of segmented mirrors can produce different wave-front when they have same position error. Moving along the Z axis, the inner mirrors influence most while the outer ones influence smallest; tilt along the X axis, middle ones have maximum wave-front aberration while the outer ones produce minimum wave-front aberration. When tilt along Y axis, middle segmented mirrors have the smallest wave-front aberration and outer ones have maximum. Two methods are used to distribute the wave-front aberration onto each segmented mirror. One is that according to the relationship curves, distribute the position error to each segmented mirror alone. Another is that each one has same position errors. The final result shows that the former method has a more relax position error when generates the same wave-front aberration.



## 1. Introduction

Spatial resolution is an important index to evaluate the observation capability of an optical system. The higher spatial resolution is, the stronger ability to distinguish the target details is, and the more information is obtained. According to the Rayleigh criterion [1], the system resolution can be improved by enlarging the aperture, but that will increase the size of primary mirror, too. Large aperture primary mirror's material preparation, processing and adjustment are all difficult. Sparse-aperture optical system solves above problems [2,3]. By using segmented mirrors to montage a large aperture of primary mirror, and the segmented mirrors are folded before launch to reduce the volume. Boeing designed an optical system of six 2.2 m segmented mirrors in the Low Cost Space Imager program, and the structure of the system uses a Golay-6 structure, which can achieve 0.29 m resolution at the orbital of 6100 km height. However, when segmented mirrors are unfolded in the orbit, the deployed position cannot be completely consistent with the design position, resulting in displacement, tilt and other errors affect the image quality of system [4,5]. In order to ensure the imaging quality, the position error of segmented mirrors is necessary to be analyzed in a real optical model instead of a theoretical model. Because theoretical

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**Table 1**
Design parameters of optical system.

| Orbit | Resolution | Focal length | Pixel size | Field of view | Wavelength |
|---|---|---|---|---|---|
| 36000 km | 3m | 250000 mm | 10 µm × 10 µm | 0.02° × 0.02° | 500–800 nm |

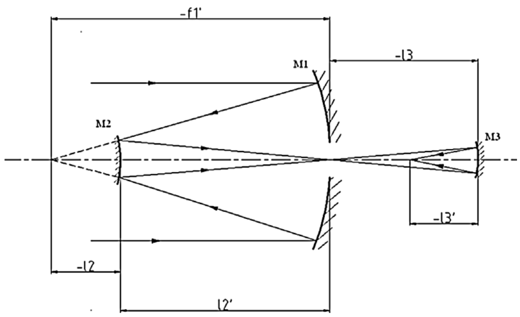


**Fig. 1.** Schematic diagram of three mirror initial structure.

**Table 2**
Optical system parameters after optimization.

| | Semi-diameter *R*/mm | Distance *D*/mm | Conic *k* |
|---|---|---|---|
| Primary Mirror | −32738.7472 | −14532.2878 | −0.9951 |
| Second Mirror | −4275.8866 | 16673.1624 | −1.6960 |
| Third Mirror | −4938.9785 | −3776.8763 | −0.7256 |
| Fold Mirror | infinite | 4000 | – |
| Image | infinite | 0 | – |

model is an ideal model, it could not consider the system's aberration [6,7]. By using software to design a real optical system, distribute a large aperture primary mirror into 9 circle mirrors. Adjust each segmented mirror's position errors, and we can get relationship curves between position errors of segmented mirrors and the wave-front aberration or Strehl ratio. Analyzing the relationship curves can obtain optical system's imaging quality's sensitivity to the segmented mirrors' position error, including displacement error, tilt error and piston. According to the relationship, the total RMS can be distributed into different values to different layers. For example, tolerance on movement along X axis is tighter to middle segmented mirrors than the outer and inner ones, which makes some tolerance on segmented mirrors more loose relative to give each one uniform tolerance.

## 2. Optical system design and imaging quality analysis

To analyze the influence of sparse-aperture optical system, design a three mirror system. Requirements are listed as follows (Table 1):

### 2.1. Initial structure of optical system

There are two kinds of structures to design a reflective system: refractive-reflective and reflective types [8]. The disadvantages of refractive-reflective type are large volume and limited aperture. Reflective type has no chromatic aberration, which can be imaged in a wide band; less number of mirrors [9]. According to the design requirements as follows: long focal length, large aperture, small field of view, so reflective optical system is chosen. Fig. 1 shows the initial structure of three mirror system. $M_1$, $M_2$, $M_3$ forms the whole system, in which $R_1$, $R_2$ and $R_3$ are the radius of the $M_1$, $M_2$, $M_3$, respectively; $d_1$ is the distance from $M_1$ to $M_2$, and $d_2$ is the distance from $M_2$ to $M_3$; $k_1$, $k_2$ and $k_3$ are conics of three mirrors [10].

$h_1$, $h_2$, $h_3$ are the apertures of the $M_1$, $M_2$, $M_3$, respectively; f'is the focal length of the $M_1$; $l_2$ is distance from the center point of $M_2$ to focus of $M_1$; $l'_2$ is distance from center point of $M_2$ to focus of $M_1$ and $M_2$; $l_3$ is distance from the center point of the $M_3$ to the focus of $M_1$ and $M_2$; $l'_3$ is distance from center point to focus of optical system. According to the formulas of initial optical system parameters and system requirements, we can solve all the parameters of the initial structure.

According to the actual needs, select the appropriate parameters to optimize the design. Stop is put on primary mirror, and a flat mirror is put in the front of the third mirror to make the optical system compact. Finally, structural parameters can be obtained after optimization (Table 2, ).