Design of visible/infrared double-band spectral imager

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Abstract. OFFNER hyperspectral imager using convex grating as spectral splitting component has many merits including large relative aperture, no smile, small key stone, compact construction and easier assembly and etc, has widely used in many occasions of various fields. Design of double-band hyperspectral imager using OFFNER structure is presented in this paper. SHAFER fore telescope system and convex grating imaging are adopted, groove etching density is different in different region on the same substrate for different spectral band, and different diffractive order is used respectively to split the two spectral bands. The optical system achieves good image quality in wide spectral range, compact construction and small volume. And all the reflective curved face are sphere, moderate tolerances are good for the processing and alignment.

1. Introduction

Hyperspectral imager, which is used on space sensing platform, combines the imaging technique and spectroscopy to achieve hyper-spectral images of target scene[1]. Since the hyperspectral concept was first put forward by Goetz about twenty years ago, several hyperspectral imagers were developed all over the world, and several imagers were used on orbit successfully. For the eximious information achievement ability, the hyperspectral technique has gained broad attention and fast development, and has extensive prospect in many fields such as military scout, satellite remote sensing, geological survey and resource survey in agriculture, forestry and mining. And in recent years, it has applied many times successfully in deep space exploration[2].

As the continuously deepen of space remote sensing technique and flourish development of small satellite, the requirement for performance and miniaturization of the spectral imager is higher. The hyperspectral imager needs to achieve high resolution in large breadth in order to shorten the access period and achieve more abundant spectral information at the same time. The hyperspectral imager needs also to be miniaturization and light weight to be seasoned with variety of platform and detection need. The types of hyperspectral imagers consists of prism dispersion spectrometer, grating spectrometer and fourier spectrometer according to the imaging principle. Traditional dispersion method in which prism and grating is insert into the collimated beam has the disadvantages of large smile and heavy weight. OFFNER spectrometer arised in recent years covered the shortages, and has the merits including large relative aperture, no smile, small keystone, compact construction and simplified assembly[3]. OFFNER spectrometer has already used successfully in many explorers for deep space detection[5]-[8].
2. Spectrometer based on OFFNER configuration

OFFNER spectrometer was developed from the coaxial three-mirror relay optical system presented by OFFNER in 1973. There are two types of configurations of the OFFNER spectrometer including convex grating and curved face prism. Hyperion and COIS of American adopted convex grating to separate the spectrum, CHRIS of ESA adopted the curved prism to achieve the images of slit for different spectrum bands. The typical configuration of OFFNER spectrometer is shown in fig.1.

![Fig.1 Structural sketch map of Offner imaging spectrometer](image)

Optical system of the hyperspectral imager need to achieve small smile and keystone, that is to say, the deviation of the curved image of different spectrum from the straight line must be small, the magnification of the image of different spectrum should be consistent. The smile means that the images of slit at different wavelength is not a straight line but a curve when the slit image through the imaging system at different wavelength. The smile is usually expressed by the deviation between the link of two terminal points and the center. The keystone is caused by the different magnification of different wavelength, which will result in that the image points are not on the straight line vertical to the slit but a diagonal. The keystone will result in that the image points of different wavelength is not on the same column of pixels on the detector, which will bring about difficulties to the after data processing\(^9\). Compared with the traditional methods that grating and prism are insert into the collimated beam, OFFNER system resolves the difficulty of smile, the key stone is also ignored, large field with no field curves and small volume are achieved at the same time\(^10\).

3. Design of double-band spectral imager

3.1. Formatting the title Optical system and grating design

The wavelength of the spectrometer designed in this paper range from 0.45~5μm, including near infrared spectrum 0.45~1μm and infrared spectrum 1~5μm, the requirements for the image quality, volume and weight is high. And because of the broad wavelength range, the transmission of the lens materials varies as the temperature changes, so reflective optical system is adopted after compared with the optical systems of foreign spectrometers. A small reflective optical system is presented based on considering the domestic processing capability. The optical system designed is shown in fig.2.

The optical system adopted SHAFER fore telescope system and convex grating imaging, in which the SHAFER fore telescope system is composed of the reversal BURCH telescope and OFFNER relay optics, and the BURCH telescope optical system consists of principle mirror, fold mirror and second mirror which are used to eliminate the spherical aberration and coma aberration. We can achieve good image quality at the position of slit after the incident rays pass through the SHAFER fore telescope system, then we can achieve the image of slit on the CCD for the wavelength 0.45~1μm and on the IRFPA for the wavelength 1~5μm. And the OFFNER relay optics is laid along the direction Y, the OFFNER spectrometer is laid along the direction X, the two detectors is laid long the direction Y.
The field angle of the hyperspectral imager is 3, and the focal length is 150mm, the angle resolution is 0.4mrad, the spectrum resolution can reach 2~10nm. The IRFPA adopted HgCdTe infrared detector with the pixel dimension of $40\mu m \times 40\mu m$, and the CCD adopted Thomson-CSF TH7896 detector with the pixel dimension of $20\mu m \times 20\mu m$, in which two pixels is combined in order to match the resolution of two spectrum bands.

**Table.1 Optical system initial configuration parameters**

| Surf | Rad/mm | Thi/mm | Glass  | Tilt X/° | Tilt Y/° | Dec X/mm |
|------|--------|--------|--------|----------|----------|----------|
| 1    | Infinity | 150    | -      | 0        | -        | -        |
| 2    | -227   | -145   | MIRROR | -5.7     | -        | -        |
| 3    | Infinity | 45     | MIRROR | 20       | -        | -        |
| 4    | 422    | -49    | MIRROR | -24      | -        | -        |
| 5    | 81     | 42     | MIRROR | 11       | -        | -        |
| STO  | 57     | -50    | MIRROR | -21      | -        | -        |
| 7    | 89     | 107    | MIRROR | 12       | -        | -        |
| 8    | -      | 0      | Break  | -        | -        | 10       |
| 9    | -39    | -23    | MIRROR | 0        | -        | -        |
| 10   | -31    | 23     | GRATING| 0        | -        | -        |
| 11   | -47    | -48    | MIRROR | 0        | -        | -        |
| 12   | -      | 2.2    | Break  | -        | 0        | 0        |

The initial configuration parameters are shown in tab.1. the dichroic method in this paper is not sue-fields or prism, but the method in which groove etching density is different in different region on the same substrate for different spectral band, and different diffractive order is used respectively to separate the two spectral band. The simply configuration and compact construction will win more space for supporting and weight. Besides, all the reflective surfaces including the grating face are sphere, the tolerances are moderate, which is good for processing and alignement.

Spectral splitting of two bands is realized through the method that the groove etching density are different in different region, and different diffractive orders are employed for the different bands. The Sketch map of grating etching is shown in fig.4. The etching density for the visible and near visible band id 96lp/mm, the etching density for the visible and near visible band id 60lp/mm, reflective film is coated in order that only infrared spectrum can be reflected in infrared region, and only visible band can be reflected in visible region.
3.2. Image quality estimation

The modulation transfer function for the different bands is shown in fig.4 and fig.5, we can see the image quality is very good. The spot diagrams for two different bands in respect fields are shown in fig.6 and fig.5, the diameter of the spot of visible band is within the range of one pixel. Some of the spots’ diameters of infrared band have exceeded the range of one pixel, but 95% of the energy is within the dimension of one pixel, which can also satisfied the need of application.
4. Conclusion
Performance, volume and weight are needed to be taken into consideration for the design of spectrometer optical system. The optical system designed in this paper adopted OFFNER structure which uses convex grating as dispersive element, spectral splitting and diffraction can be realized through on grating. The results shows that the modulation transfer function and spots are better than the requirements. Reflective optical system will be more suitable for the space circumstance on orbit. Small volume and compact structure are all achieved compared with the traditional spectral splitting methods of sue-fields and prism.

5. Reference
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