Design of resolution testing facility for ultraviolet imager

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We present a resolution testing system of ultraviolet (UV) imager. In this system, an UV Czerny-Turner monochromator with a small f-number is designed to get more energy as an UV radiation source, and its stray light is rejected effectively by light traps. And UV diffuser is employed in order to get uniform light distribution on the resolving power test target. We also design a novel UV collimator which makes infinite UV testing targets. It can reduce the difficulty of optical design and the machining cost, and utilize UV energy at maximum extent. This facility has been applied in the imaging quality evaluation of the UV instrument, and the results accord with the theoretical analysis.

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There are many evaluations of imaging quality in visible and infrared wavelengths, for example, optical modulation transfer function (MTF), spatial resolution, signal-to-noise ratio (SNR) performance, and so on[1−3]. However, there are few methods capable of measuring ultraviolet (UV) optical instruments in UV band. Hence, image quality evaluations of UV instruments have to be performed in visible band, and some error and distortion cannot be avoided in the testing results. Resolution testing can provide imaging quality information of optical instrument and show numeric results. It is easy for us to make quantitative measurements and comparisons. A resolution testing facility of UV optical instrument is developed, which can realize imaging quality evaluation of UV optical instruments in UV band.

If an optical system is taken as an information transfer system, it could reflect the imaging quality by the intensity contrast attenuating characterization responding to the intensity separation, different distances, and different grating line widths. The resolution of array detector also relates to the intensity and the contrast of the targets. Using Fourier analysis, we can get the image illumination distribution on the focal surface as[4]

$$g'(x) = \frac{A}{2} + \mathrm{MTF}(f_0)\frac{2A}{\pi}\left[\cos(2\pi f_0 x) - \frac{1}{3}\cos(2\pi(3f_0)x) + \frac{1}{5}\cos(2\pi(5f_0)x) \pm \cdots\right], \quad (1)$$

where A is the vibration amplitude, f_0 is the fundamental frequency, and x is the line coordinate.

In space-filtering analysis, the higher harmonics are cut off because of the restriction of optical aperture, and then more and more components of higher harmonics are cut off as the decrease of fringe separation and width. Furthermore, SNR and optical aberration of optical system contribute to the contrast of image. Consequently, the contrast of image descends gradually.

For incoherent sources of equal intensity, the Rayleigh criterion of resolution is that the central maximum of one source falls on the first minimum of the other source. This result is a pronounced intensity dip between the peaks of the two point spread functions (PSFs). The separation of the two PSFs is simply the radius of the first dark ring, which can be evaluated as

$$\mathrm{Sep} = 1.219670\lambda(f/\mathrm{No.}), \quad (2)$$

where λ is the light wavelength, No. means the f-number. And the contrast ratio of the distinguished points is defined as

$$C = \frac{E_{\max} - E_{\min}}{E_{\max}} = 26\%, \quad (3)$$

where $E_{\max}$ and $E_{\min}$ denote the maximum and minimum light intensities, respectively.

The resolution testing facility is composed of UV monochromator, flat illuminated target, beam collimating system, and data acquisition system. The monochromator is a Czerny-Turner monochromator focal length[5] with the focal length of 0.78 m designed specifically to cover the wavelength range from 200 to 400 nm. The dispersion element is a 1200-g/mm plane reflectance grating, 60×60 (mm) in size, Al coated with $\mathrm{MgF_2}$. The image space f-number of the monochromator is 4. The principal specifications of the resolution testing system are summarized in Table 1.

The resolution testing system of UV imager is shown in Fig. 1. The merits designed in the system are summarized as follows. A large relative aperture design is adopted in the monochromator system in order to make energy from bigger spatial angle illuminate the

Table 1. General System Specifications

Spectral Coverage	200 − 400 nm
Wavelength Width (FWHM)	5 nm
Plane Reflectance Grating	1200 g/mm, Blaze Angle 10.4°
Collimator Aperture	Φ20 mm
Relative Aperture of Collimator	1:12
Non-Parallelism	20″
Stray Light Rejection	4%

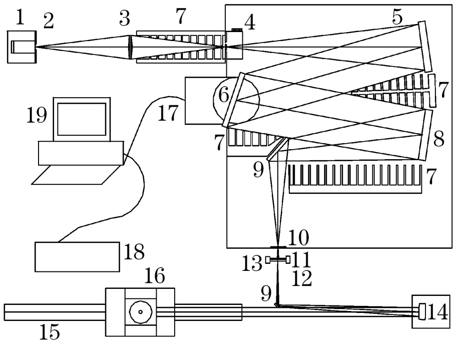

Fig. 1. Scheme of resolution testing system. 1: deuterium lamp; 2: iris aperture; 3: quartz condenser; 4: slit device; 5: reflective collimator; 6: blazed diffraction grating; 7: light trap; 8: imaging reflector; 9: flat mirror; 10: changeable slit; 11: UV diffuser; 12: resolution power test target; 13: 2D adusting plate; 14: off-axis parabolic mirror; 15: guide track; 16: UV imager platform; 17: wavelength drive mechanism; 18: image acquisition system; 19: computer.

Fig. 2. Photograph of the UV imager.

diffraction grating sufficiently[6,7]. Moreover, all the reflective mirrors are coated with Al+MgF_2 reflective coating whose reflectance exceeds 80%. Many stray light traps are designed[8−11] with the help of ZEMAX, which not only reject the stray light sufficiently, but also make the monochromaticity better[12]. The stray light rejection is under 4%. An UV diffuser is added between exit slit and resolution power test target, which makes the target be illuminated more uniformly. An off-axis parabolic mirror is adopted as collimator, which reduces the design difficulty and machining cost, and utilizes UV energy at maximum extent. The reflective mirror matches fore system and we get an infinite UV resolution target for resolution test.

This method has been applied in the image evaluation of our UV imager (see Fig. 2). The working spectrum of our UV imager is 340 − 380 nm, effective focal length 15.4 mm, entrance pupil 10 mm. The UV imager is assembled on the testing platform, and the image of UV resolution target is captured by the image acquisition system. The limiting resolution spatial frequency is defined as the maximum spatial frequency at which the apparent luminance between the bars is still noticeably different from the apparent luminance of the bars. Due to the physical condition of the observer, we analyzed the different bars in the image by software. If the contrast of the bars is greater than 26%, we consider this resolution target can be resolved, otherwise we will change the testing position of the resolution target. Three-bar resolution charts are shown in Fig. 3, in the standard U.S. Air Force format.

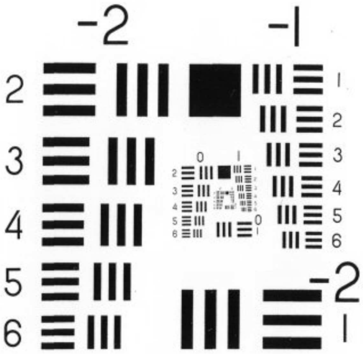

Fig. 3. Three-bar resolution charts.

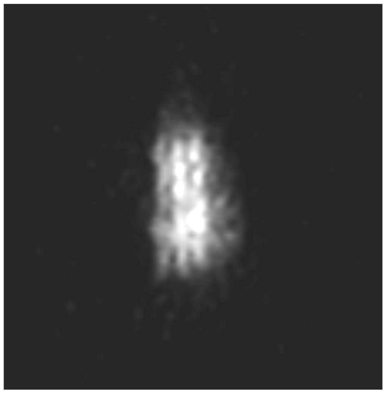

Fig. 4. Test result of the UV imager.

Each spatial frequency is represented by a pair of orthogonal three-bar charts, and the spatial resolution is given by

$$N_c = 2^{\left(k+\frac{m-1}{6}\right)} \quad (\mathrm{lp/mm}). \tag{4}$$

So, we can get the spatial resolution of UV imager by

$$N = N_c f_c'/f', \tag{5}$$

Where f_c' is the effective focal length of the off-axis parabolic collimator, f' is that of the UV imager.

The test result of our UV imager is shown in Fig. 4. The contrast of the bars is greater than 26%, when $k = 0$ and $m = 3$. In this case, we can get the resolution of the UV imager by combining Eqs. (4) and (5), and setting $f_c' = 240$ mm: $N_c = 1.26$ lp/mm, $N = 19.6$ lp/mm.

The spatial resolution of our UV imager is 19.6 lp/mm, and the linear resolution of the optical system is greater than 19.6 lp/mm.

In conclusion, a resolution testing facility of UV optical instrument is developed. It works in UV band, so that the error and distortion which cannot be avoided in conventional methods will be no longer a problem. Our testing facility and analysis could be extended to all UV instruments, regardless of whether they are imaging or scanning electro-optical systems.

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