宽光谱可见-短波红外成像光学系统设计

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摘 要: 针对目前的红外成像光学系统在机器视觉工业检测领域难以同时实现成像质量好和结构紧凑设计的问题,提出了一种宽光谱可见-短波红外成像光学系统的设计方法。运用光学设计软件 ZEMAX 设计了一种适用于可见光和短波红外的红外成像光学系统。该系统由 7 组 10 片透镜组成,利用多组双胶合透镜来消色差,在第 15 个面使用非球面提高成像质量,最后对系统的成像质量进行研究。设计结果表明:该系统的的工作波长为 0.4~1.7 μm,全长为 79.6 mm,*F* 数为 2.8,焦距为 25.7 mm,畸变小于 1.4%,调制传递函数值在奈奎斯特频率 100 lp/mm 处均大于 0.4 ,接近衍射极限,成像质量良好。该系统可以对光滑表面的装配件进行缺陷检测,具有结构简单、易于加工装调的优点,有助于高效地完成机器视觉检测。

关键词: 宽谱段; 光学设计; 可见光成像; 红外成像; 机器视觉
中图分类号: O435 **文献标志码:** A **DOI:** 10.3788/IRLA20220638

0 引 言

[1−2]

[5]

2015 [6] 0.75~1.0 μm

[3] ±15°

2022

0.75~1 000 μm [7] 0.4~0.7 μm

[4] 10

1~2.5 μm 100 mm

ZEMAX -

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7 10

79.6 mm H-LAF54 CAF2

H-K9 L

0.4~1.7 μm

1 光学系统选型

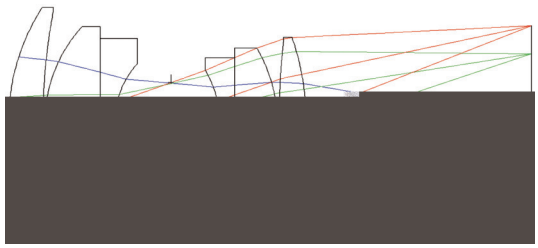
1.1 光学系统结构选型

[8]

(1)

[9]

1



1

Fig.1 Reflective optical system structure

(2)

[9]

2

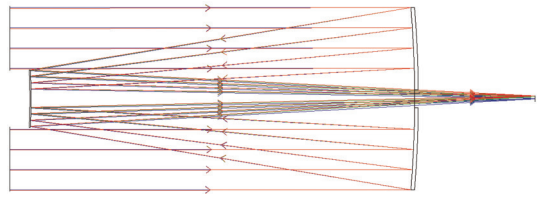
(3)

2

Fig.2 Schematic diagram of a reflective optical system

3

-



3

Fig.3 Catadioptric optical system structure

CMOS 3.45 μm
2/3 in (1 in=2.54 cm) 0~50 ℃

1

表 1 光学系统性能参数

Tab.1 Optical system performance parameters

Parameter	Value
Wavelength/μm	0.4-1.7
Focal length/mm	25.7
Field of view 2ω	9.3
F number	2.8
Total length of system/mm	79.6

PW

[12]

2.2 像差校正及优化评价

1

ZEMAX

ZEMAX

1.2 非球面面型参数的求解

[10]

$$z=\frac{cr^2}{1+\sqrt{1-(1+k^2)c^2r^2}}+Ar^4+Br^6+Cr^8+Dr^{10}+\cdots \tag{1}$$

c A B C D

4 6 8 10 k

$k>0$ $k=0$ $-1<k<0$

$k=-1$ $k<-1$

ZEMAX

[10]

2 系统光学设计

2.1 镜头总体设计指标及初始结构确定

(1)

(2) PW

(3)

(4) (5) (6)

[11]

-

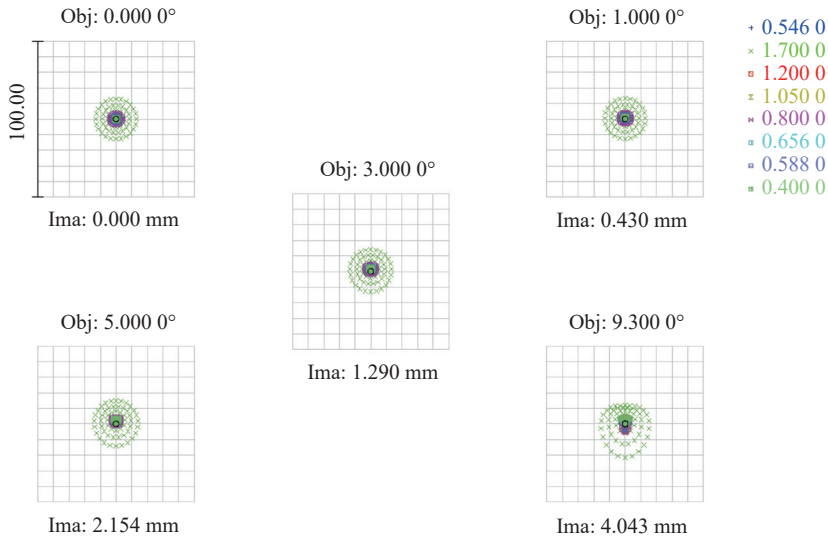
F

2 448 pixel×2 048 pixel

- 4 10
4 79.6 mm 9.9 mm *F*
7 10 2.8
5 -
RMS 5.623 μm
GEO 26.431 μm
5

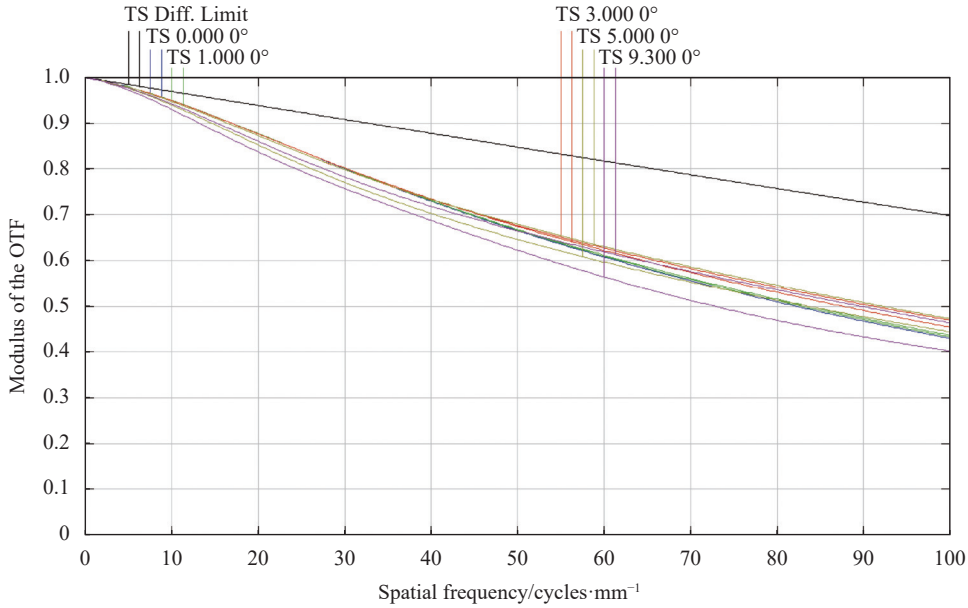
4

Fig.4 Optical system structure diagram 6 -



5

Fig.5 Optical system spot diagram



6

Fig.6 Modulation transfer function curve

7 -

100 lp/mm MTF 0.4 0.1 mm 1.4%

7

Fig.7 Astigmatism, field curvature and distortion curves

3 可行性分析

3.1 公差分析

100 lp/mm MTF 0.559

0.554 0.333 0.481 0.052 90%

MTF≥0.410 50% MTF≥0.427 10%

MTF≥0.540 MTF

[13]

[14]

8

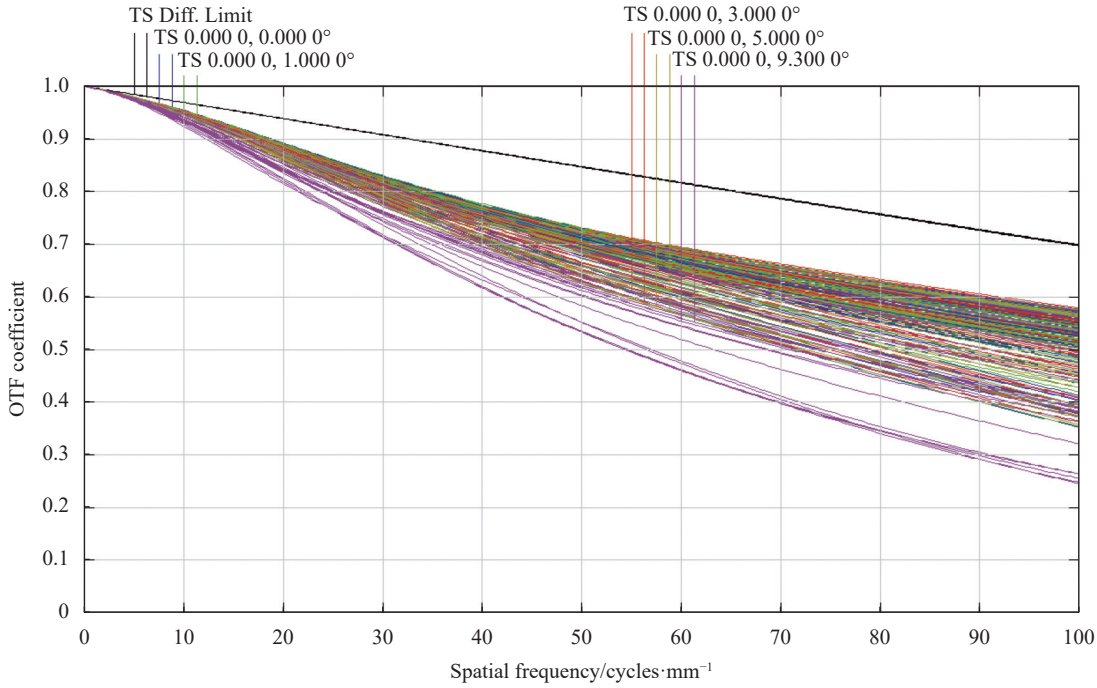
MTF

9 100 MTF

2

8

Fig.8 Preset tolerance values



9 MTF

Fig.9 MTF curve of Monte Carlo analysis

表 2 蒙特卡洛分析结果

Tab.2 Monte Carlo analysis results

Analysis item	Result	Trial
Best	0.553 733 13	-
Worst	0.332 685 05	97
Mean	0.480 631 74	20
Standard deviation	0.052 099 53	-
Compensator statistics	-	-
Change in back focus	-	-
Minimum	−0.060 978	-
Maximum	0.060 626	-
Mean	−0.000 021	-
Standard deviation	0.023 908	-
90%	≥0.408 031 81	-
50%	≥0.490 294 20	-
10%	≥0.539 641 55	-

3.2 实验论证

10

10 (b1)

10 (a1)

1 450~1 900 nm

SWIR

10 (b2)

10 (a2) SWIR

SWIR

10 -

Fig.10 SWIR-visible imaging comparison diagram

4 结 论

0.4~1.7 μm -

7 10

100 lp/mm 0.4

F 2.8 1.4%

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Design of optical system for wide-spectrum visible-short wave infrared imaging

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Abstract:

Objective The industrial lens for machine vision inspection needs not only to meet the design requirements of lightweight and large field of view, but also have high luminous flux. In this paper, based on the needs of machine vision engineering applications, an optical system for wide-spectrum visible-short wave infrared imaging is designed using the optical design software ZEMAX. The Wide spectrum visible-short wave infrared imaging

system can operate in the band of 0.4-1.7 μm. The system is composed of 7 groups of 10 lenses. The MTF value is greater than 0.4 at the Nyquist frequency of 100 lp/mm. The *F* number of the system is 2.8, and the distortion is less than 1.4%. All kinds of aberrations have been well corrected and balanced. And the system has good imaging performance. It has certain reference value for the design of similar optical systems.

Methods The optical system structures are usually divided into refractive system, reflective system and hybrid system. Different optical system structures have their own advantages and disadvantages. According to the imaging performance of the system and the cost-performance ratio in industrial applications, the refractive system can meet the requirements of large field of view, low distortion and compact structure. The refractive system is used to observe through refraction of transmitted light, so it is widely used in optical structure selection. At the time, by using the conventional processing and adjustment methods, it can meet the accuracy requirements. It has the characteristics of stable image quality, small stray light and high element transmittance.

Results and Discussions According to the actual needs of industrial testing, the main parameters to be considered in the structural design of the wide-spectrum visible-short wave infrared imaging optical system are lens material,