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Optics and optical instruments — Quality evaluation of optical systems — Assessing the image quality degradation due to chromatic aberrations

Optique et instrument d'optique — Évaluation de la qualité des systèmes optiques — Estimation de la dégradation de la qualité de l'image due à des aberrations chromatiques

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15795 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 1, *Fundamental standards*.

Annex A of this International Standard is for information only.

Introduction

Aberrations due to the variation of the refractive index with wavelength (dispersion) are usually termed “chromatic aberrations”. Originally, this wording was based on the fact that, in the presence of these aberrations, the image of objects such as points, lines and edges, exhibit coloured fringes in addition to the variation of luminance.

From this point of view, the concept of the point spread function (PSF) and the related optical transfer function (OTF), see ISO 9334, is basically a luminous (or more general radiative) transfer of optical information. There is only one signal regarding wavelength which is the result of the spectral transmission and sensitivity of the transmission chain, even if the latter is not identical to the relative luminous sensitivity of the human eye.

Nowadays, the terms “colour” and, more specifically, “chroma” in the domain of physical science are well defined by colorimetry according to CIE Publication Nr. 15.2 (see reference [1] in the Bibliography) and are restricted to that region of the electromagnetic spectrum, which is accessible to the normal (trichromatic) human observer.

However, when concerned with aberrations due to the dispersive behaviour of electromagnetic waves, it is necessary to take into account that the spectral region of the optical waveband is by far wider than the limits of sensitivity of the human eye. This region may extend from the UV to the medium IR. In such applications, the human visual process is not involved or, if so, only by means of certain translations of the information into the visual waveband.

Nevertheless, the fact of variation of the form and position of the point or line spread function with wavelength or with some spectrally weighted wavebands is still given. To characterize this dispersive behaviour, one has not to deal with colorimetry, but should describe the position and extent of the spread function relative to that of a certain reference wavelength or reference spectral weighting.

In this sense, the present International Standard will not deal with colour sensations, but the term “chromatic aberrations” is used in a purely physical manner to describe the wavelength dependent properties of such aberrations.

The variation of the spread function with wavelength in a given image plane of an optical system may be characterized by a lateral translation and additionally by a variation in form and width.

The lateral translation of a typical coordinate point of the spread function will be called lateral chromatic aberration, whereas the form and extent can be characterized by two numbers derived from a weighting procedure over the spread function (edge width).

The longitudinal chromatic aberration indicates the axial position of the best image plane for a certain wavelength or waveband with respect to a reference plane and for a defined focusing (or image quality) criterion.

Optics and optical instruments — Quality evaluation of optical systems — Assessing the image quality degradation due to chromatic aberrations

1 Scope

This International Standard defines terms relating to chromatic aberrations and indicates the mathematical relationships between those terms.

It also gives general guidance for the measurement of chromatic aberrations and is valid for optical imaging systems which are constructed to be of rotational symmetric imaging geometry. It is also valid for optoelectronic imaging systems.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 9334:1995, *Optics and optical instruments — Optical transfer function — Definitions and mathematical relationships*

ISO 9335:1995, *Optics and optical instruments — Optical transfer function — Principles and procedures of measurement*

ISO 9039:1994, *Optics and optical instruments — Quality evaluation of optical systems — Determination of distortion*

ISO 11421:1997, *Optics and optical instruments — Accuracy of optical transfer function (OTF) measurement*

3 Symbols and units

Symbol	Meaning	Unit	Specified in
λ	Measurement wavelength	nm, µm	4.2.1
λ_r	Reference wavelength	nm, µm	4.3
$W(\lambda)$	Weighted spectral distribution	dimensionless	4.2.2
$W_R(\lambda)$	Weighted spectral reference distribution	dimensionless	4.3
$u(\lambda)$	Local image field coordinate for measurement wavelength	µm	4.5
$u(\lambda_r)$	Local image field coordinate for reference wavelength	µm	4.5
$u(W)$	Local image field coordinate for weighted spectral measurement distribution	µm	4.5

Symbol	Meaning	Unit	Specified in
$u(W_R)$	Local image field coordinate for weighted spectral reference distribution	µm	4.5
$h'(\lambda_r)$, $h'(W_R)$	Image height for reference wavelength or distribution	mm	4.5
$T(\lambda)$	Lateral chromatic aberration	µm	4.6
$T(W)$	Weighted lateral chromatic aberration	µm	4.7
$L(\lambda)$	Longitudinal chromatic aberration	µm	4.9
$L(W)$	Weighted longitudinal chromatic aberration	µm	4.9
LE	Left edge width	µm	4.8.2
RE	Right edge width	µm	4.8.2
EW	Edge width	µm	4.8.2
$z'(\lambda)$, $z'(\lambda_r)$	Position of best focus for wavelengths λ and λ_r	mm	4.9
$z'(W)$, $z'(R)$	Position of best focus for spectral weightings $W(\lambda)$ and $W_R(\lambda)$	mm	4.9
ω'_p	Image pupil field angle	degree	3.8 of ISO 9039:1994
ω_p	Object pupil field angle	degree	3.7 of ISO 9039:1994
OTF(r)	One-dimensional optical transfer function	dimensionless	3.11 of ISO 9334:1995
MTF(r)	One-dimensional modulation transfer function	dimensionless	3.9 of ISO 9334:1995
PTF	Phase transfer function	degree, rad	3.10 of ISO 9334:1995
PSF	Point spread function	mm^{-2}	3.5 of ISO 9334:1995
LSF	Line spread function	mm^{-1}	3.13 of ISO 9334:1995
ESF	Edge spread function	dimensionless	3.14 of ISO 9334:1995
ψ	Azimuth	degree	4.21 of ISO 9334:1995
ϕ	Reference angle	degree	4.12 of ISO 9334:1995
ξ	Integration variable	dimensionless	4.5

4 Terms and definitions, principle and mathematical relationships

4.1 General

For the purposes of this International Standard, the terms and definitions given in ISO 9334 and ISO 9335 apply.

4.2 Wavelengths and spectral distributions

For the determination of chromatic aberrations, several wavelengths or spectral distributions shall be given for which the aberrations are to be determined.

4.2.1 Quasi-monochromatic measurement

In this case, the spectral bandwidth of the measurement radiation is small compared to the distance between neighbouring measurement wavelengths.

The measurement wavelength under consideration is the mean wavelength of that quasi-monochromatic radiation for which the chromatic aberrations are to be determined.

4.2.2 Measurement with finite spectral bandwidth

The spectral bandwidth is specified by a spectral weighting function, $W(\lambda)$. For the purpose of analytical calculations, this shall be approximated by spectral area weighting with different discrete wavelengths. The measurements of chromatic aberrations shall always be carried out in the same manner, regardless of whether they are determined for discrete wavelengths or for certain wavebands.

4.3 Reference wavelength and weighted spectral reference distribution

In the case of quasi-monochromatic radiation (see 4.2.1), the reference wavelength, λ_r, is the wavelength to which the determination of the chromatic aberrations is related. In the case of finite spectral bandwidth (see 4.2.2), the reference spectral distribution is the spectral weighting function, $W_R(\lambda)$, to which the determination of the chromatic aberrations is related.

4.4 Measurement plane

The measurement plane is a plane perpendicular to the optical axis in which the measurement is carried out. It may be defined by geometric means, or with the help of a suitably defined focusing criterion, which can be applied by measurement and shall be accessible for analytical calculations.

4.5 Image heights and local image field coordinates

The image heights are defined by means of the line spread function (LSF). Figure 1 shows an example of (measured) line spread functions.

For the definition of line spread function, see 3.13 of ISO 9334:1995. This definition is also valid for weighted spectral distribution, $W(\lambda)$.

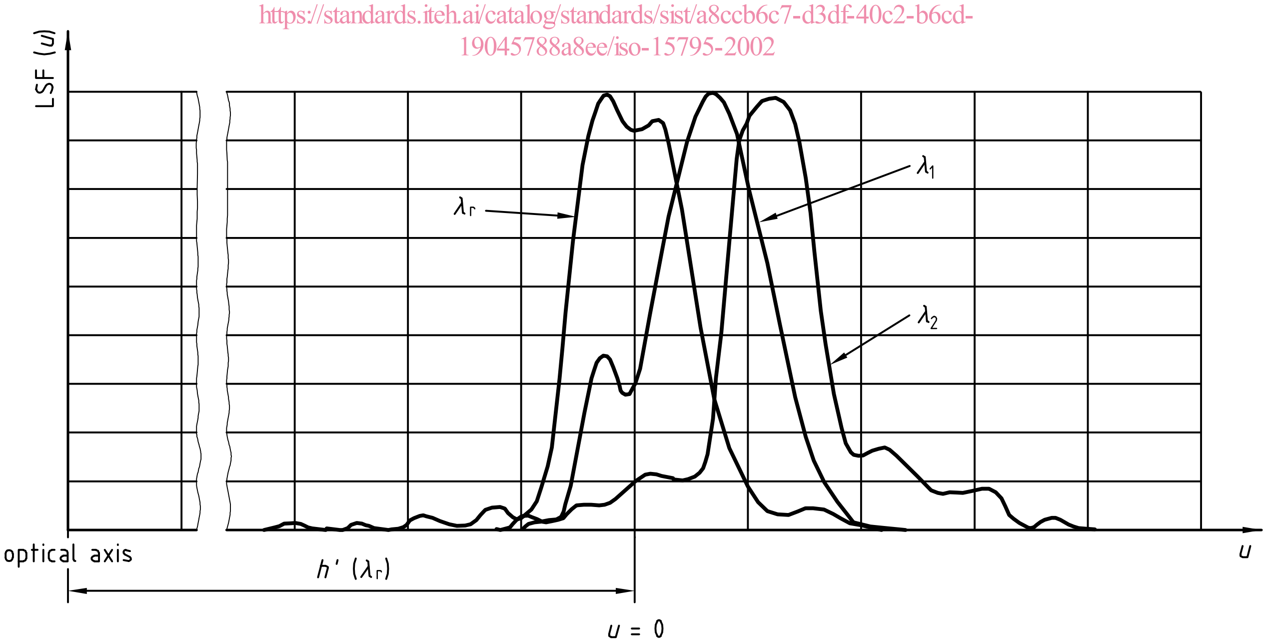

Figure 1 — Examples for quasi-monochromatic line spread functions

The image height, h', is the position within the line spread function where the area fractions of the line spread function are equal.

Thus:

$$\int_{-\infty}^{h'} \mathrm{LSF}\,(\xi)\,\mathrm{d}\xi = \frac{1}{2}\int_{-\infty}^{+\infty} \mathrm{LSF}\,(\xi)\,\mathrm{d}\xi \qquad (1)$$

where ξ is an integration variable.

Local image field coordinates, u, are introduced by choosing the origin $u = 0$ at the reference image height, $h'(\lambda_r)$, for the reference wavelength, λ_r, or $h'(W_R)$ for the weighted spectral reference distribution, $W_R(\lambda)$.

4.6 Lateral chromatic aberration

The lateral chromatic aberration, $T(\lambda)$, is defined as the radial variation in image height for the wavelength, λ, relative to the image height for the reference wavelength, λ_r. This definition requires a numerical evaluation of the line spread function, as it is also necessary for the determination of the optical transfer function. For given magnification ratio and relative aperture, the lateral chromatic aberration is a function of wavelength and image height.

For finite image distance, the lateral chromatic aberration, $T(\lambda)$, in the measurement plane is given by:

$$T(\lambda) = u(\lambda) - u(\lambda_r) \qquad (2)$$

where

$u(\lambda_r) = 0$.

4.7 Weighted lateral chromatic aberration

The weighted lateral chromatic aberration, $T(W)$, is defined as the radial variation in image height, $u(W)$, for the weighted spectral distribution, $W(\lambda)$, relative to the image height, $u(W_R)$, for the weighted spectral reference distribution, $W_R(\lambda)$. For given magnification ratio and relative aperture, the weighted lateral chromatic aberration in the measurement plane is a function of image height.

For finite image distance:

$$T(W) = u(W) - u(W_R) \qquad (3)$$

where

$u(W_R) = 0$.

As in 4.6, this requires a numerical evaluation of the line spread function, here with weighted spectral distribution, $W(\lambda)$.

4.8 Form and extent of the edge spread function (ESF)

4.8.1 General

In addition to the lateral chromatic aberration as a displacement between the median values of the edge spread functions for the reference and measurement wavelength or spectral weighting, one shall judge the degradation in image quality with the help of the form of the line or edge spread function for the different wavelengths or spectral weightings. This will give information in the space domain alternatively to the optical transfer function in the spatial frequency domain. The edge spread function will be used, because, in general, its structure is relatively, simple. See Figure 2.

For the definition of edge spread function, see 3.14 of ISO 9334:1995. This definition is also valid for weighted spectral distribution, $W(\lambda)$.

The edge spread function may be derived from the line spread function by:

$$\mathrm{ESF}\,(u) = \int_{-\infty}^{u} \mathrm{LSF}\,(\xi)\,\mathrm{d}\xi \qquad (4)$$

where ξ is an integration variable.

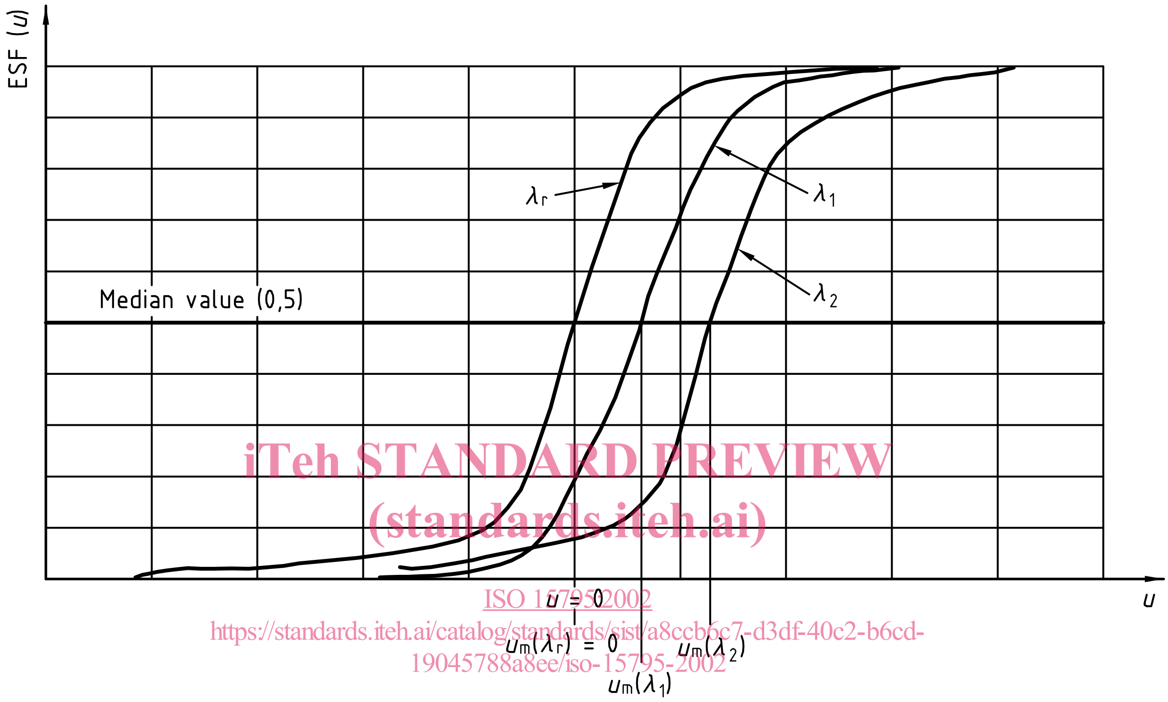

Figure 2 — Examples for quasi-monochromatic edge spread functions

The image height, h', is the median value of the normalized edge spread function.

From the edge spread function, two overall quality criteria in space domain are deduced: left edge width (LE) and right edge width (RE). (See references [2] and [3] in the Bibliography.)

4.8.2 Edge widths

The edge widths shall be defined with the help of the area between real edge spread function ESF(u) and the ideal edge [Heaviside step function H(u)]. The step of the ideal edge lies in the median of the edge spread function (u_m: ESF(u) = ½). With this definition, the two areas between both functions will be minimal. See Figure 3 and reference [3] in the Bibliography.

Definitions of the edge widths are as follows:

$$\mathrm{LE} = 2\int_{-\infty}^{u_\mathrm{m}} \mathrm{ESF}\,(u - u_\mathrm{m})\,\mathrm{d}u \qquad (5)$$

$$\mathrm{RE} = 2\int_{u_\mathrm{m}}^{+\infty} \left[1 - \mathrm{ESF}\,(u - u_\mathrm{m})\right]\mathrm{d}u \qquad (6)$$

$$\mathrm{EW} = \mathrm{RE} + \mathrm{LE} \qquad (7)$$