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Photography — Electronic still picture imaging — Resolution and spatial frequency responses

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Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 42, *Photography*.

This fourth edition cancels and replaces the third edition (ISO 12233:2017), which has been technically revised.

The main changes are as follows:

— In Clause 6 and Annex C, the e-SFR test chart has been modified by replacing the “slanted square” features with four-cycle “slanted star” features, to enable diagonal measurements in addition to horizontal and vertical measurements.

— In Clause 6 and Annex D, the e-SFR algorithm has been modified by using a Tukey window, by using a 5th-order polynomial equation to fit the edge, and by correcting for the edge-angle sampling. As a result, the measurement results may be slightly different compared to the results obtained using the 3rd edition.

— Clause 6 and Annex D were updated to clarify the steps in the e-SFR algorithm.

— In Annex C, the reflectances of the surround and the light and dark patches were clarified.

— Annexes J, K, L, and M were added.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Purpose

The spatial resolution capability is an important attribute of a digital camera. Resolution measurement standards allow users to compare and verify spatial resolution measurements, as described in Reference [14]. This document defines terminology, test charts, and test methods for performing resolution measurements for analogue and digital cameras.

Technical background

Because digital cameras are sampled imaging systems, the term *resolution* is often incorrectly interpreted as the number of addressable photoelements. While there are existing protocols for determining camera pixel counts, these are not to be confused with the interpretation of resolution as addressed in this document. Qualitatively, resolution is the ability of a camera to optically capture finely spaced detail, and is usually reported as a single valued metric. Spatial frequency response (SFR) is a multi-valued metric that measures contrast loss as a function of spatial frequency. SFR is similar to the optical transfer function (OTF) and the modulation transfer function (MTF) which are defined for linear systems (see References [1] and [3]). Generally, contrast decreases as a function of spatial frequency to a level where detail is no longer visually resolved. This limiting frequency value is the resolution of the camera. A camera's resolution and its SFR are determined by several factors. These include, but are not limited to, the performance of the camera lens, the number of addressable photoelements in the optical imaging device, and the camera image processing, which can include image sharpening, image compression and gamma correction functions.

While resolution and SFR are related metrics, their difference lies in their comprehensiveness and utility. As articulated in this document, resolution is a single frequency parameter that indicates whether the output signal contains a minimum threshold of detail information for visual detection. In other words, resolution is the highest spatial frequency that a camera can usefully capture under cited conditions. It can be very valuable for rapid manufacturing testing, quality control monitoring, or for providing a simple metric that can be easily understood by end users. The algorithm used to determine resolution has been tested with visual experiments using human observers and correlates well with their estimation of high frequency detail loss.

SFR is a numerical description of how contrast is changed by a camera as a function of spatial frequencies. It is very beneficial for engineering, diagnostic, and image evaluation purposes and serves as an umbrella function from which such metrics as sharpness and acutance are derived. Often, practitioners will select the spatial frequency associated with a specified SFR level as a modified non-visual resolution value.

In a departure from the first edition of this document, two SFR measurements were described in the second edition. The first SFR metrology method, an edge-based spatial frequency response (e-SFR), was identical to that described in the first edition, except that a lower contrast edge was used for the test chart. The test chart used for the e-SFR measurement has been updated in this fourth edition, to enable measurements in diagonal directions. Regions of interest (ROIs) near slanted vertical, diagonal, and horizontal edges are digitized and used to compute the e-SFR levels. The use of a slanted edge allows the edge gradient to be measured at many phases relative to the image sensor photoelements and to yield a phase averaged e-SFR response.

A second sine wave based SFR (s-SFR) metrology method was introduced in the second edition. Using a sine wave modulated target in a polar format (e.g. Siemens star), it is intended to provide an SFR response that is more resilient to ill-behaved spatial frequency signatures introduced by the image content driven processing of some consumer digital cameras. In this sense, it is intended to enable easier interpretation of SFR levels from such cameras. Comparing the results of the edge-based SFR and the sine-based SFR might indicate the extent to which nonlinear processing is used.

The first step in determining visual resolution or SFR is to capture an image of a suitable test chart with the camera under test. The test chart should include features of sufficiently fine detail and frequency content such as edges, lines, square waves, or sine wave patterns. The test charts defined in this document have been designed specifically to evaluate digital cameras. They have not necessarily been designed to evaluate other electronic imaging equipment such as input scanners, CRT displays, hard-copy printers, or electro-photographic copiers, nor individual components of an electronic still-picture camera, such as the lens.

The measurements described in this document are performed using digital analysis techniques. They are also applicable with analogue outputs of the camera by digitizing the analogue signals, if there is adequate digitizing equipment.

Methods for measuring SFR and resolution — Selection rationale and guidance

This section is intended to provide more detailed rationale and guidance for the selection of the different resolution metrology methods presented in this document. While resolution metrology of analogue optical systems, by way of spatial frequency response, is well established and largely consistent between methodologies (e.g. sine waves, lines, edges), metrology data for such systems are normally captured under well-controlled conditions where the required data linearity and spatial isotropy assumptions hold. Generally, it is not safe to assume these conditions for files from many digital cameras, even under laboratory capture environments. Exposure and image content dependent image processing of the digital image file before it is provided as a finished file to the user prevents this. This processing yields different SFR responses depending on the features in the scene or in the case of this document, the test chart. For instance, in-camera edge detection algorithms might specifically operate on edge features and selectively enhance or blur them based on complex nonlinear decision rules. Depending on the intent, these algorithms might also be tuned differently for repetitive scene features such as those found in sine waves or bar pattern targets. Even using the constrained camera settings recommended in this document, these nonlinear operations can yield differing SFR results depending on the test chart. Naturally, this causes confusion on which test charts to use, either alone or in combination. Guidelines for selection are offered below.

Edges are common features in naturally occurring scenes. They also tend to act as visual acuity cues by which image quality is judged and imaging artefacts are manifested. This logic prescribed their use for SFR metrology in the past and current editions of this document. It is also why edge features are prone to image processing in many consumer digital cameras: they are visually important. All other imaging conditions being equal, camera SFRs using different test chart contrast edge features can be significantly different, especially with respect to their morphology. This is largely due to nonlinear image processing operations and would not occur for strictly linear imaging systems. To moderate this behaviour, in the second edition of ISO 12233, a lower contrast slanted edge feature was chosen to replace the higher contrast version of the first edition. The edge feature was further modified in this fourth edition, to enable measurements in diagonal directions. This “slanted star” feature choice still allows for acuity amenable SFR results beyond the half-sampling frequency and helps prevent nonlinear data clipping that can occur with high contrast target features. It is also a more reliable rendering of visually important contrast levels in naturally occurring scenes. However, data clipping is still possible when using a test chart having a large edge reflectance ratio and/or when the captured image of the test chart is significantly overexposed. This data clipping can cause the measured e-SFR values to be overstated.

Sine wave features have long been the choice for directly calculating the MTF of analogue imaging systems and they are intuitively satisfying. They were introduced in the second edition based on experiences from the edge-based approach. Because sine waves transition more slowly than edges, they are not prone to being identified as edges in embedded camera processors. As such, the ambiguity that image processing imposes on the SFR can be largely avoided by their use. Alternatively, if the image processing is influenced by the absence of sharp features, more aggressive processing might be used by the camera. Using the sine wave starburst test pattern (see Figure 6) adopted in the second edition along with the appropriate analysis software, a sine wave based SFR can be calculated up to the half-sampling frequency. For the same reasons stated above, the sine wave-based target is also of low contrast and consistent with that of the edge-based version. An added benefit of the target’s design over other sine targets is its compactness and bi-directional features.

Experience suggests that there is no single SFR for today’s digital cameras. Even under the strict capture constraints suggested in this document, the allowable feature sets that most digital cameras offer prevent such unique characterization. Confusion can be reduced through complete documentation of the capture conditions and camera settings for which the SFR was calculated. It has been suggested that comparing edge-based and sine wave-based SFR results under the same capture conditions can be a good tool in assessing the contribution of spatial image processing in digital cameras. See Reference [14].

Finally, at times a full SFR characterization is simply not required, such as in end of line camera assembly testing. Alternately, SFR might be an intimidating obstacle to those not trained in its utility. For those in need of a simple and intuitive space domain approach to resolution using repeating line patterns, a visual resolution measurement is also provided in this fourth edition of this document.

With such a variety of methods available for measuring resolution, there are bound to be differences in measured resolution results. To benchmark the likely variations, the committee has published the results of a pilot study using several measurement methods and how they relate to each other. These results are provided in Reference [18].

Photography — Electronic still picture imaging — Resolution and spatial frequency responses

1 Scope

This document specifies methods for measuring the resolution and the spatial frequency response (SFR) of electronic still-picture cameras. It is applicable to the measurement of both monochrome and colour cameras which output digital data or analogue video signals.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14524, *Photography — Electronic still-picture cameras — Methods for measuring opto-electronic conversion functions (OECFs)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
addressable photoelements
number of active photoelements in an *image sensor* (3.11)

Note 1 to entry: This equals the product of the number of active photoelement lines and the number of active photoelements per line.

3.2
aliasing
output image artefacts that occur in a *sampled imaging system* (3.31) due to insufficient sampling

Note 1 to entry: These artefacts usually manifest themselves as moiré patterns in repetitive image features or as jagged stair-stepping at edge transitions.

3.3
cycles per millimetre
cy/mm
spatial frequency unit defined as the number of spatial periods per millimetre

3.4
edge spread function
ESF
normalized spatial signal distribution in the *linearized* (3.15) output of an imaging system resulting from imaging a theoretical infinitely sharp edge