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Photography — Digital cameras — Geometric distortion (GD) measurements

Photographie — Caméras numériques — Mesurages de distorsion géométrique (DG)

Reference number
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Contents

Page

Foreword

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

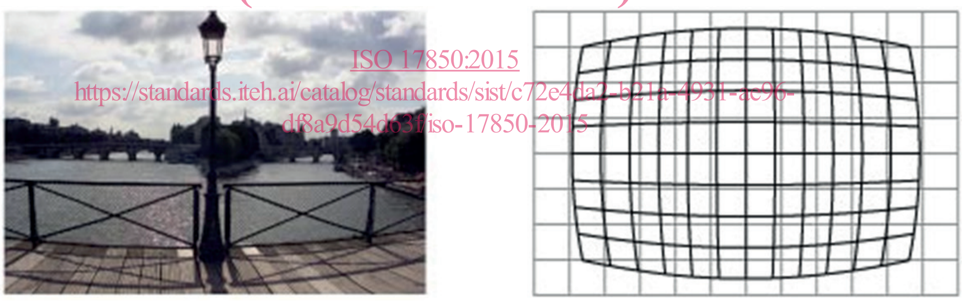
The committee responsible for this document is ISO/TC 42, *Photography*.

Introduction

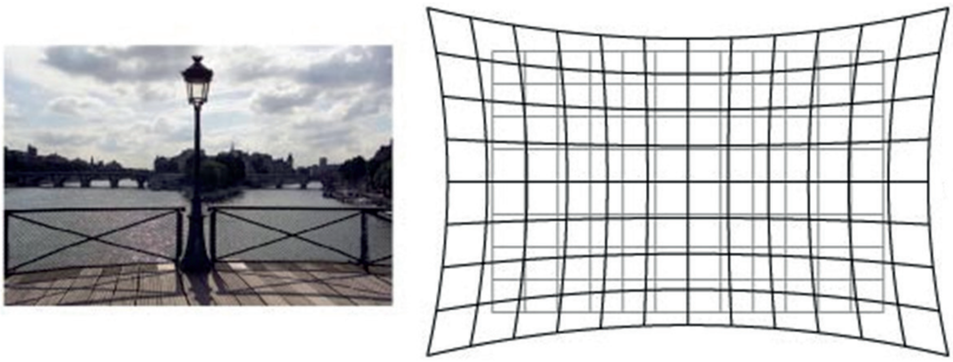
A digital still camera (DSC) typically employs a taking lens that is a rotationally symmetric optical system. Generally, the function of rotationally symmetric optical systems is to form an image that is geometrically similar to the object except some particular systems, such as fish-eye lenses and eyepieces, where this condition is deliberately not maintained. This function is accomplished ideally according to the geometry of perspective projection. Departures from the ideal image geometry are called distortion. The distortion is a position-dependent quantity which generally has a vectorial character. In a given image plane (which may also lie at infinity), this vector, representing the difference between theoretical and real image position, has a radial and a tangential component. In optical systems, the tangential component is basically conditioned by imperfect rotational symmetry. The systems manufactured in accordance with the present state of the art have a negligible tangential distortion.

Geometric distortion (GD) of DSCs is mainly caused by the variation of magnification in the image field of the camera lens. The most well-known effect of distortion is that straight lines appear curved. Generally speaking, the proportions between objects are not preserved in a distorted image, which can be very unpleasant for some natural scenes, architecture, or portraits. Distortion is fully described by a 2D map, giving the displacement from a point in an ideal undistorted image to the point in the actual distorted image. The image centre is usually assumed to be undistorted; the magnification factor at this position actually defines the focal distance.

Different types of distortion are usually characterized by how the magnification radially varies within the image field. Barrel and pincushion are the most usual types of distortion for which magnification is respectively monotonously decreasing and monotonously increasing when moving along from the centre to the border of the image field. Other types which cannot be categorized into above two types are usually called wave distortion.



a) Barrel (or negative) distortion



b) Pincushion (or positive) distortion

NOTE The magnification is decreasing for barrel distortion and increasing for pincushion.

Figure 1 — Two main types of distortions

ISO 9039 defines methods to measure a lens that is separated from a camera. On the other hand, this International Standard was developed and defines methods to measure the total image distortion of a camera including a lens and signal processing.

This International Standard is based on both Reference [3] prepared by the Camera Phone Image Quality (CPIQ) group within the International Imaging Industry Association (I3A) and Reference [4] prepared by Camera and Imaging Products Association (CIPA).

Photography — Digital cameras — Geometric distortion (GD) measurements

1 Scope

This International Standard specifies a protocol to measure geometric distortion of a digital camera. It is applicable to the measurement of digital cameras including camera phones.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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)*.

IEC 61146-1, *Video cameras (PAL/SECAM/NTSC) — Methods of measurement — Part 1: Non-broadcast single-sensor cameras*

EBU Tech3249, *Measurement and analysis of the performance of film and television camera lenses*

3 Terms and definitions

3.1
geometric distortion
GD
<of DSC> displacement from the ideal shape of a subject (lying on a plane parallel to the image plane) in the recorded image

Note 1 to entry: Geometric distortion basically derives from variation of lateral magnification in the image field of a camera lens and results in straight lines being rendered as curves. There are other factors to induce geometric distortion, for example, rotational asymmetricity of a camera lens or position shift processing in a camera imaging process.

3.2
image height

3.2.1
image height
<of DSC> distance between an image point and the centre of the image area or its relative expression which is the value normalized by one half of the diagonal of the image area

Note 1 to entry: This is an extension of the definition in ISO 9039 which is a measurement for optical systems.

3.2.2
actual image height
<of DSC> image height of an actual recorded image point in the recorded image area

Note 1 to entry: “Actual recorded image point” corresponds to “observed image point” in ISO 9039.

Note 2 to entry: “Image height” in ISO 9039 basically means “actual image height” but the usage is sometimes confusing.

Note 3 to entry: The adjective “actual” is used in similar meaning, “actual point” and “actual position”, for example.

3.2.3
ideal image height
<of DSC> image height of a theoretical corresponding point in the recorded image area, assuming a geometrically undistorted image formation

Note 1 to entry: This is an extension of the definition in ISO 9039 which is a measurement for optical systems.

Note 2 to entry: The adjective “ideal” is used in similar meaning, “ideal point” and “ideal position”, for example.

3.3
image quality
impression of the overall merit or excellence of an image, as perceived by an observer neither associated with the act of photography nor closely involved with the subject matter depicted

Note 1 to entry: The purpose of defining image quality in terms of third-party (uninvolved) observers is to eliminate sources of variability that arise from more idiosyncratic aspects of image perception and pertain to attributes outside the control of imaging system designers.

3.4
noise
unwanted variations in the response of an imaging system

3.5
resolution
measure of the ability of a digital image capture system or a component of a digital image capture system to distinguish picture detail

3.6
TV distortion
line distortion measured by conventional method of TV field defined in IEC 61146-1 (24 Geometric distortions) or EBU Tech3249 (2.11. Picture height distortion)

4 Measurement methods

4.1 General

As defined in 3.1, geometric distortion basically derives from the variation of magnification in the image field. If this phenomenon occurs in an image, it means that a regular structure in an object does not appear to be regular in the image taken with the camera. There are two ways defined in this International Standard to quantify the amount of geometric distortion in an image. Both have their pros and cons.

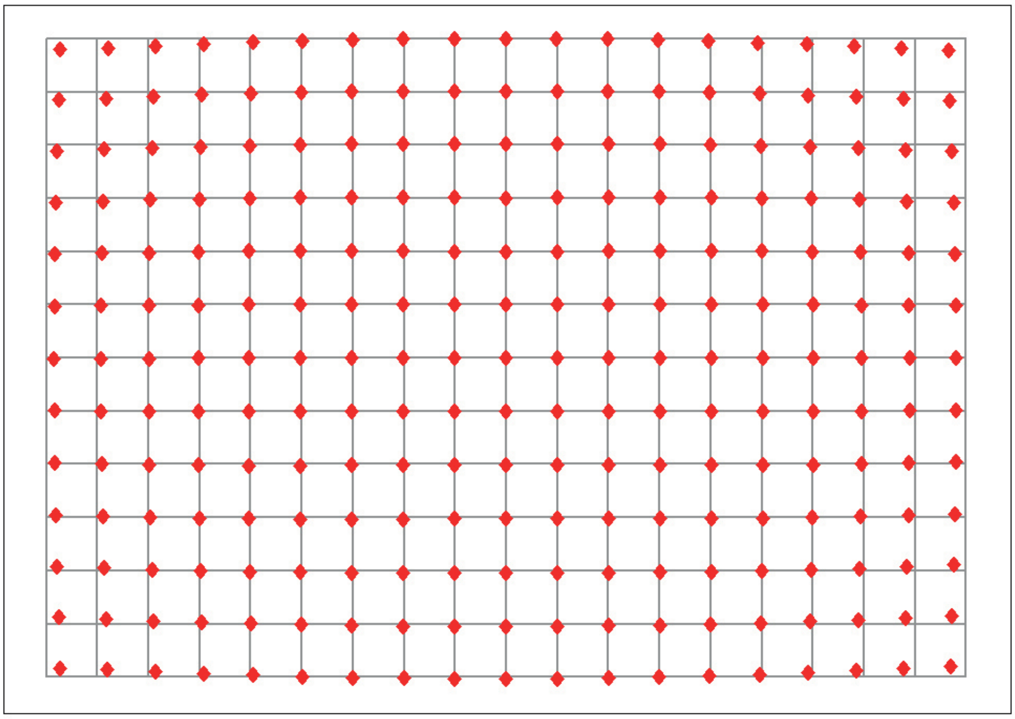


Figure 2 — Regular grid (solid lines) in the scene is distorted and the red diamonds mark the position of the intersections in the image produced by the camera

4.2 Local geometric distortion

Geometric distortion can be measured on a white chart containing black dots at the position of a regular grid or on a grid chart formed by straight lines. The local geometric distortion method analyses the grid formed by the test chart in the centre of the image and calculates the ideal positions of the structure based on the measured distances. After that, it analyses the rest of the image and locates all actual positions of the grid. The distance between the ideal position and the actual position is the geometric distortion at that location in the image.

The distance between the two positions can be plotted as a function over the distance to the image centre. This curve indicates the variation of image magnification versus the actual image height, which is an expression of the geometric distortion called local geometric distortion. In order to limit the result to a single value that might get reported with the cameras specifications, the maximum (peak to peak) value shall be reported.

The manufacturing tolerances, such as lens tilt or off-centring, can result in a non-rotationally symmetric GD behaviour. If the system is not rotationally symmetric, it can lead to increased distortion levels in the image corners. In this case, the measured geometric distortion is correct for the camera under test but might not represent a standard camera of the tested model.

4.3 Line geometric distortion

The principle of line geometric distortion is to measure the bending of a straight horizontal or vertical line at defined distances from the image centre and to report the maximum of the measured bending. This bending is preferably measured on a chart with a regular line grid.

Line geometric distortion is the direct measured result of this method and it is easy to understand intuitively for consumers. However, it can also be interpreted from the measured result using the local geometric distortion method.

NOTE The line geometric distortion has a long history and it has been used in the video technology for decades. The reason is that it was easy to determine this value with standard measurement equipment used in the analogue video world. The fundamental concept of this method was first standardized by the IEC in IEC 61146–1 in 1994.

5 Requirements

5.1 Apparatus and hardware

The following hardware is necessary to control and report the test conditions:

— dot target or a grid chart;

— two light sources;

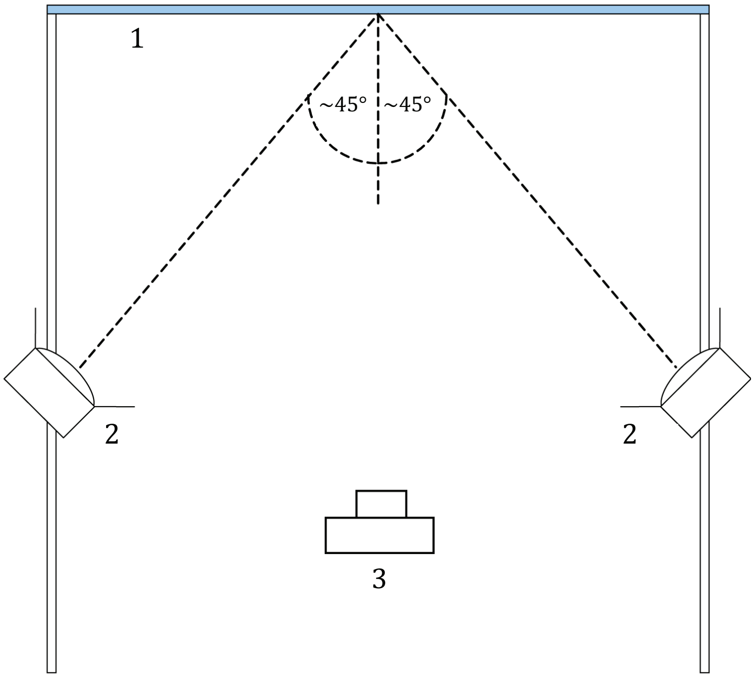
— device to measure the chart height captured in the image;

— mirror (for camera alignment with the target).

5.2 Lighting

Lighting uniformity is recommended to ease the processing of the target but does not influence the phenomenon of distortion. The light sources should be adjusted such that illumination is uniform on the target at ±10 %. Light sources should be baffled to prevent the direct illumination of the camera. The light sources should be located so as to minimize the occurrence of specular reflections off the surface of the target when viewed by the camera under test.

The illumination should be set so that the auto-exposure of the camera gives a suitable result. More precisely, the image should not be clipped in either bright or dark parts of the target. The camera should be positioned so that it casts no shadow on the chart.



Key

1 test target

2 illumination

3 camera

Figure 3 — Lighting system

5.3 Dot chart

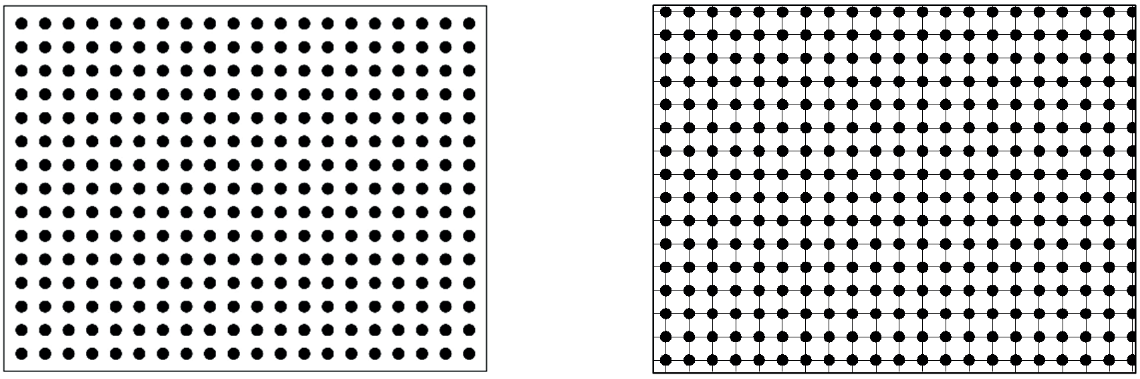
5.3.1 Design and characteristics

The test chart contains black circular dots placed on a perfectly regular square grid on a uniform white background.

The dot centres may be connected by straight black lines with a thickness of approximately 1/10 of the dot diameter as shown in Figure 4 b). That way, it does not affect the dot detection but helps to better align the camera to the chart for example, by eliminating rotation between the chart and camera's image sensor axes. The straight black lines are especially useful if the mirror method described in 5.5.4 is not possible or available.

The chart can be either a reflective test chart, which is front illuminated, or a transparency test chart, which is rear illuminated. The chart contrast level should at least be 40:1 and not be higher than 10 000:1.

The size and the number of dots should depend on the resolution of the camera and the shooting distance. The chart shall be shot compliant with the condition specified in 5.5.3.



a) Simple dot chart b) Dot chart with connecting lines

Figure 4 — Dot chart

5.3.2 Requirement for the chart planarity

Non-planarity can be caused by bending of a chart.

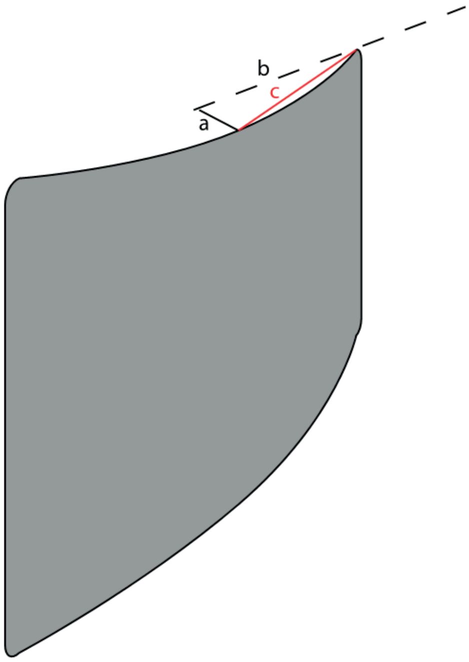
Requirement for the chart planarity is as follows.

Surface deviation which is a height or depth from the reference plane [indicated as bending “a” in Figure 5 a)] shall be less than 1,5 % of the width of the chart.

The required accuracy for a specific measurement sets the requirement for the chart planarity as follows.

For small bending, c is equal to half the width of the chart to which all numbers are normalized. If bending a occurs in a chart, the effective chart width seen by the camera is b. The difference between c and b causes the deviation in % measured due to the bending of the chart and calculated by (1-b/c) × 100.

The standard requirement for local geometric distortion measurement should be a maximum error of 0,045 % due to deviation in planarity of the chart. This equals a maximum deviation in planarity of 3 %. And 3 % of half the width equals to 1,5 % of the full width of the chart.



Deviation in %	a/c	b/c = cos (sin^{-1} a/c)	Deviation of measured distortion in %
0,5	0,005	0,999 987	0,001 3
1	0,01	0,999 950	0,005 0
2	0,02	0,999 800	0,020 0
3	0,03	0,999 550	0,045 0
4	0,04	0,999 200	0,080 0
5	0,05	0,998 749	0,125 1
6	0,06	0,998 198	0,180 2
8	0,08	0,996 795	0,320 5
9	0,09	0,995 942	0,405 8
10	0,1	0,994 987	0,501 3

a) Explanation of the parameters **b) Table of numerical relation**

Figure 5 — Explanation for the chart planarity and its effect on measured value

5.4 Grid chart

5.4.1 Design and characteristics

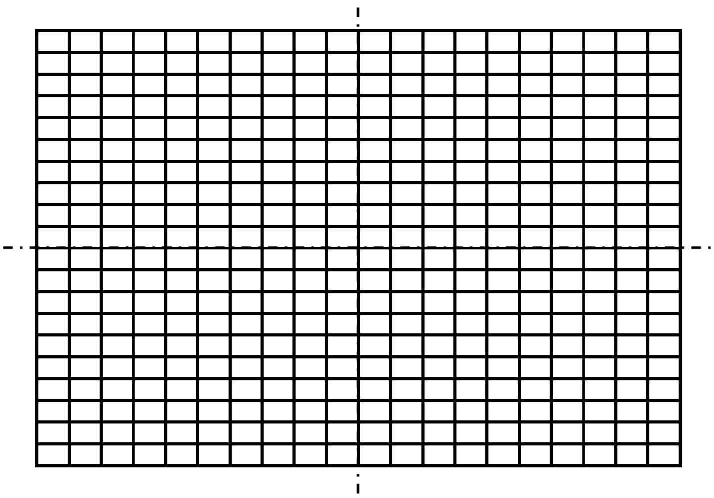


Figure 6 — Line grid pattern chart

The line grid pattern chart shown in Figure 6 is an example of a test chart for line distortion. The horizontal and vertical lines of the grid shall be located between reference lines at no less than 1,0, 0,9, 0,8, 0,7, and 0,6 times the distance between the pairs of reference lines with the tolerance of ±2 %. The pairs of reference lines are the sides of the outermost rectangle.

The chart shall be shot compliant with the condition specified in 5.5.3.

All other aspects regarding size and contrast shall be as described for the dot chart in 5.3.

5.5 Image/camera settings

5.5.1 General

Set the camera at minimal gain to minimize noise (if possible). All special colour modes or tone mode should be deactivated. Quality factors, if available, should be set to their maximum.

5.5.2 Basic settings and influencing factors

The magnification is an important factor in measuring the distortion. The standard shooting distance should be 30 times the focal length equivalent to 35 mm film camera. This means that a chart height of 720 mm fills the complete image. If the chart height differs more than 30 % from this requirement, the chart height captured in the image shall be reported together with the results.

The camera shall be accurately focused on the chart.

Since distortion depends on the wavelength, it also depends on the illuminant and the spectral responses of the sensor. Only the distortion on the green channel shall be reported.

5.5.3 Specific test procedures

5.5.3.1 Local geometric distortion

The chart shall be shot so that

— chart shall fill the field of view,

— number of dots should be no less than 15 dots in height and the related number of dots depending on the image aspect ratio (for 4:3, 20×15 dots; for 3:2, 23×15) to form a regular grid,

— diameter of each dot should be no less than 10 pixels, and

— in case of reporting the single value as ISO local geometric distortion (see 7.2), and when using the method of measuring actual dots, the corner 4 dots in the output image shall be positioned so that the centre of each dot is on a vertex of the frame of the output image with the tolerance of 0 %, −2 % (i.e. the centre of each dot is positioned from 98 % to 100 % at the actual image height).

5.5.3.2 Line geometric distortion

The chart shall be shot so that each reference line pair inscribes the frame of the output image with the tolerance of 0 %, −2 % (i.e. the contact points of the reference line pair and the frame are positioned from 98 % to 100 % at the picture height or at the picture width).

5.5.4 Positioning of the camera

The chart shall be orthogonal to the optical axis. The alignment can be performed by using a mirror set up on the target plane (i.e. parallel to the target plane), as shown in Figure 7.

Pan, tilt, and laterally displace the camera position to the left, right, up, and down until the centre point of the taking lens in the viewfinder image is positioned at the image centre.

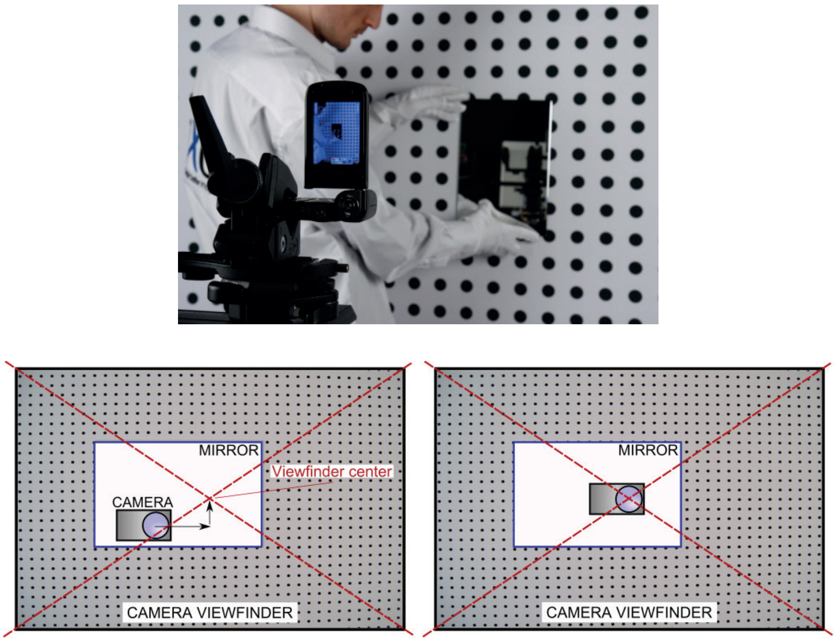


Figure 7 — Alignment of the camera with the target plane using a mirror

If the mirror is not available or the positioning method is not applicable, a manual alignment using the straight lines in the chart shall be performed so that the intersection of the central horizontal and vertical lines of the chart is in the centre of the image. For each horizontal/vertical line, the lines shall be oriented “parallel” to the horizontal/vertical image borders meaning that the line shall be at the same image height for the same distances from the vertical/horizontal centre of the image.

5.5.5 Exposure, white balance, and focus

The exposure shall be set by automatic exposure or set to an exposure level such that the uniform white background becomes 110 to 160 (8-bit digital).

For a colour camera, the white balance shall be in a variable white balance mode or an automatic white balance mode. The camera white balance should be adjusted, if possible, to provide proper white balance for the illumination light source as specified in ISO 14524.

The focusing shall be adjusted in focus by a proper way, for example, a manual-focusing mode or an auto-focusing mode.