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Automatic identification and data capture techniques — Bar code symbol quality test specification — Direct part mark (DPM)

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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 document 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 or www.iec.ch/members_experts/refdocs).

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This document was prepared by Joint Technical Committee ISO/JTC 1, *Information Technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

This second edition cancels and replaces the first edition (ISO/IEC 29158:2020), which has been technically revised.

The main changes are as follows:

— the definition of continuous grading has been deleted (it is now defined in ISO/IEC 15415);

— the rounding method has been revised to always round down.

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 and www.iec.ch/national-committees.

Introduction

Direct part marking (DPM) is a technology whereby, generally, an item is physically altered to produce two different surface conditions. This alteration can be accomplished by various means including, but not limited to, dot peen, laser mark, ink jetting and electro-chemical etch. The area of the alteration is called "the mark." The area that includes the mark and background as a whole, when containing a pattern defined by a bar code symbology specification, is called "a symbol."

When light illuminates a symbol, it reflects differently depending on whether it impinges on the background of the part or on the physical alteration. In most non-DPM bar code scanning environments, light is reflected off a smooth surface that has been coloured to produce two different diffuse reflected states. The DPM environment generally does not fit this model because the two different reflected states depend on at least one of the states having material oriented to the lighting such that the angle of incidence is equal to the angle of reflection. Sometimes, the material so oriented produces a specular (mirror like) reflectance that results in a signal that is orders of magnitude greater than the signal from diffuse reflectance.

In addition, from the scanner point-of-view, some marking and printing methods generate dots and are not capable of producing smooth lines. This is important for symbologies such as Data Matrix, which is specified to contain smooth continuous lines, but can be marked with disconnected dots in DPM applications.

Current specifications for matrix symbologies and two-dimensional print quality are not exactly suited to reading situations that have either specular reflection or unconnected dots or both. Additionally, symbologies specified to consist of smooth continuous lines may appear with unconnected dots. This is intended to act as a bridge between the existing specifications and the DPM environment in order to provide a standardized image-based measurement method for DPM that is predictive of scanner performance.

As with all symbology and quality standards, it is the responsibility of the application to define the appropriate parameters of this document for use in conjunction with a particular application.

This document was developed to assess the symbol quality of direct marked parts, where the mark is applied directly to the surface of the item and the reading device is a two-dimensional imager.

When application specifications allow, this method is also potentially applicable to symbols produced by other methods. This is appropriate when DPM symbols and non-DPM symbols are being scanned in the same scanning environment. The symbol grade is reported as a DPM grade rather than as an ISO/IEC 15415 grade.

Automatic identification and data capture techniques — Bar code symbol quality test specification — Direct part mark (DPM)

1 Scope

This document describes the modifications to the symbol quality methodology defined in ISO/IEC 15415 and provides a symbology specification.

This document establishes alternative illumination conditions, some new terms and parameters, modifications to the measurement and subsequent grading of certain parameters, and the reporting of the grading results.

This document is intended for verifier manufacturers and application specification developers.

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/IEC 15415, *Information technology, Automatic identification and data capture techniques — Bar code symbol print quality test specification — Two-dimensional symbols*

ISO/IEC 19762, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 15415, ISO/IEC 19762 and the following 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
reference symbol
high-contrast printed calibration card for which results are traceable back to national or international standards and for which the supplier supplies a calibration certificate

3.2
stick
line segment comprised of image pixels that is used to connect areas of the same colour that are near to each other

4 Symbols and abbreviated terms

4.1 Symbols

C_C value of cell contrast

C_{MOD} value of cell module modulation

f_x remaining distance fraction of the x position

f_y remaining distance fraction of the y position

g current threshold of the grid-centre point histogram in the calculation of the optimal threshold according to Annex A

M_D mean of the grid-centre point histogram of the dark elements

M_L mean of the grid-centre point histogram of the light elements

M_{Lcal} mean of the light lobe from a histogram of the calibrated standard

$M_{Ltarget}$ mean of the light lobe from the final grid-centre point histogram of the symbol under test

R measured reflectance of the cell

R_{cal} reported reflectance value, R_{max}, from a calibration standard

R_{target} measured percent reflectance of the light elements of the symbol under test relative to the calibrated standard

NOTE R_{target} is graded and reported as the parameter named “minimum reflectance”.

S_{Rcal} system response parameters (such as exposure and/or gain) used to create an image of the calibration standard

$S_{Rtarget}$ system response parameters (such as exposure and/or gain) used to create an image of the symbol under test

T_1 threshold created using a histogram of the defined grey scale pixel values in a circular area 20 times the aperture size in diameter, centred on the image centre using the algorithm given in Annex A

T_2 threshold created using the histogram of the reference grey scale image pixel values at each intersection point of the grid using the method given in Annex A

T_{min} current minimum threshold in the calculation of the optimal threshold according to Annex A

T_{max} current maximum threshold in the calculation of the optimal threshold according to Annex A

V current sum of two variances according to Annex A

V_D current variance of the grid-centre point histogram of the dark elements according to Annex A

V_L current variance of the grid-centre point histogram of the light elements according to Annex A

V_{min} current minimum variance in the calculation of the optimal threshold according to Annex A

x x position on the camera image plane

x' x position on the virtual camera plane

x_p x position of image pixel on the camera image plane

y y position on the camera image plane

y' y position on the virtual camera plane

y_p y position of image pixel on the camera image plane

4.2 Abbreviated terms

CM cell modulation

CC cell contrast

CMOD cell module modulation

DFPD distributed fixed pattern damage

DPM direct part marking

FPD fixed pattern damage

TCL tilted coaxial lighting and camera position

5 Overview of methodology

5.1 Process differences from ISO/IEC 15415

All parameters in the symbology and print quality specifications apply except for:

— multi-row bar code symbols are not supported by the method described in this document;

— a different method for setting the image contrast;

— a new method for choosing the aperture size;

— an image pre-process methodology for joining disconnected modules in a symbol (where applicable);

— a different process for determining the modulation parameter which has been renamed cell modulation (CM);

— a different process for determining the symbol contrast parameter which has been renamed cell contrast (CC);

— a different process for computing FPD;

— a new parameter called minimum reflectance (R_{target});

— print growth is not graded and not included in the final grade.

This document explains how to both specify and report quality grades in a manner complementary to, yet distinct from, the method in ISO/IEC 15415.

NOTE Annex E gives a cross reference comparison of this document to ISO/IEC 15415.

5.2 Lighting

Lighting environments shall be reported in accordance with 6.2 and 10.2. The lighting environment(s) shall be selected by the application specification in consideration of the properties of the mark and the requirements of the reading equipment and environment of the application.

5.3 Tilted coaxial lighting and camera position

Tilted coaxial lighting and camera position (TCL) is useful for DPM applications that use a geometrical mark which is peened, drilled or carved into a surface. Reading camera and unidirectional illumination are located at a coaxial position with a known fixed tilt angle and object rotation angle and position.

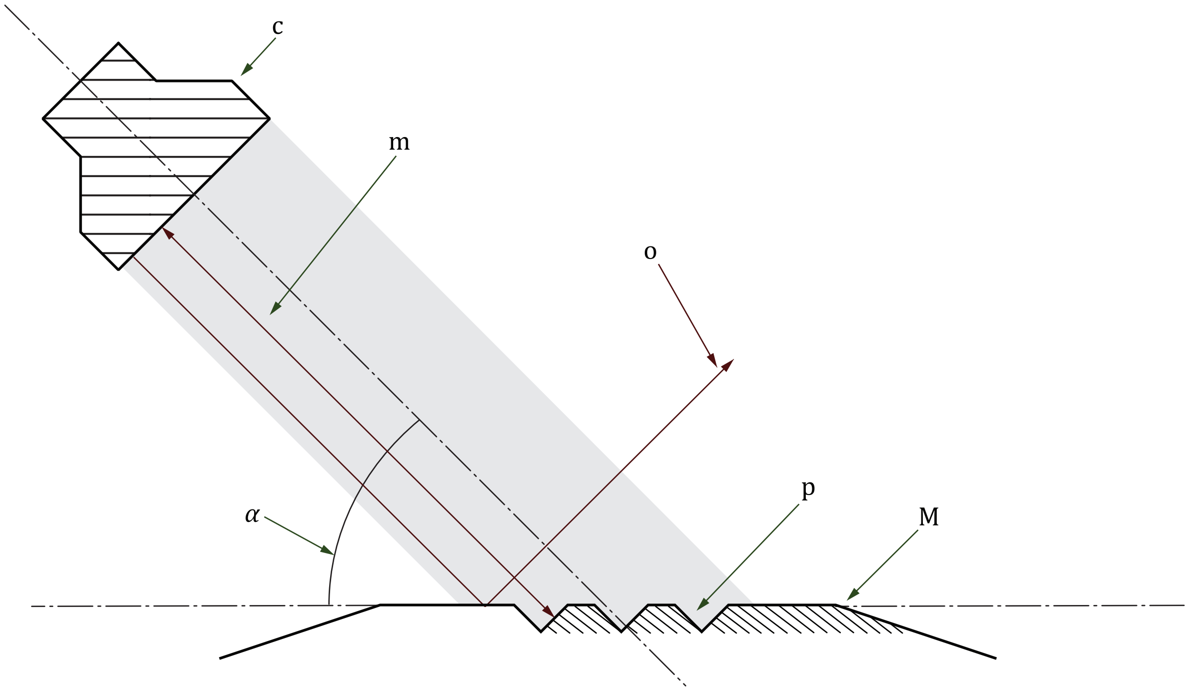
To read dot-peened codes, there are multiple reading setups possible. This document defines several camera and lighting setups in order to address various dot peen geometries.

This specific TCL environment is focussing on the system response of the mark (e.g. the image a camera sees). SAE Standard AS9132[2] takes a different approach to specify the mark geometry.

Figure 1 illustrates the setup. The essential parameter is the camera reading angle. Typical camera reading angles include 30°, 45° or 60° in relation to the plane of the mark.

NOTE 1 The camera angle is defined in a compatible way to the lighting angle of ISO/IEC 15415:2024, Figure 1.

NOTE 2 Within the dot peen industry, it is common to specify the stylus angle which is twice the camera angle given in Figure 1.



Key

c camera and coaxial lighting

m light beam in mark is reflected to camera

o light beam outside mark is reflected away

α camera reading angle

p peened mark

M marked object

Figure 1 — Tilted coaxial lighting and camera setup

This setup is referenced by the abbreviation "TCL" in the following text.

It is not feasible to grade this setup with a camera angle of 90°. The result will not be significant for this application, as other features of the marked object are measured.

Recognise that a general-purpose verifier device does not always cover this application, as it requires a special construction.

6 Obtaining the image

6.1 Camera position and symbol orientation

6.1.1 Symbol placement

Camera to object position is described in this subclause. By default, the horizontal and vertical axis of the symbol are parallel to a line formed by the edge of the image sensor within ±3° (i.e. nominally no rotation). This symbol orientation should be maintained unless an application specification requires or allows a different orientation. An application specification may specify a different symbol rotation. Since the symbol rotation is determined after decoding, the actual rotation angle should be reported so that the setup can be reproduced easily. In applications in which the rotation angle is specified, the rotation angle shall be reported to confirm conformance to specified requirements.

The part is placed such that the symbol is in the centre of the field of view.

NOTE Placing the symbol in the centre of the field of view results in the intended angle and position of illumination and camera and tends to achieve the most accurate results.

6.1.2 Camera position in a 90° camera angle set up

The camera is positioned such that the plane of the image sensor is parallel to the plane of the symbol area. This is identical to a 90° camera angle.

6.1.3 TCL setup

Within the TCL setup, camera and symbol position differs in the following points.

— The camera is positioned in the camera angle defined by the application.

— The raw image is geometrically transformed to correspond to a test image with a virtual camera position with a 90° camera angle, as described in Annex B.

— The symbol rotation angle needs to be specified by the application and shall be respected by ±5°.

6.2 Lighting environments

6.2.1 General

The lighting environment is specified by the application. This shall include a direction specifier or an angle or both. The format is an extension of the angle specifier used in ISO/IEC 15415. Several examples are given in the following subclauses.

6.2.2 Perpendicular coaxial (“90”)

The symbol is illuminated with diffuse light such that the specular reflection from the entire field of view is nominally uniform.

6.2.3 Diffuse off-axis (“D”)

A diffusely reflecting dome is illuminated from below so that the reflected light falls non-directionally on the part and does not cast defined shadows. This is commonly used for reading curved parts. The angle specifier shall be “D”.

This lighting is also called dome lighting.

6.2.4 Four direction (“Q”)

Light is aimed at the part at the given angle ±3° from the plane of the surface of the symbol from four sides such that the lines describing the centre of the beams from opposing pairs of lights are co-planar and the planes at right angles to each other. One lighting plane is aligned to be parallel to the line formed by a horizontal edge of the image sensor to within ±5°. The lighting shall illuminate the entire symbol area with nominally uniform energy. The angle specifier shall be "Q" preceded by a number specifying the angle in degrees.

EXAMPLE “45Q” (angle equal to 45°) or “30Q” (angle equal to 30°).

6.2.5 Two direction (“T”)

Light is aimed at the part at the given angle ±3° from two sides. The light may be incident from either of the two possible orientations with respect to the symbol. The lighting plane is aligned to be parallel to the line formed by one edge of the image sensor to within ±5°. The lighting shall illuminate the entire symbol area with nominally uniform energy. The angle specifier shall be "T" preceded by a number specifying the angle in degrees.

EXAMPLE “45T” (angle equal to 45°) or “30T” (angle equal to 30°).

Since there are two possible orientations in this setup (above and below, and left and right) the particular orientation actually used should be reported. The reporting method may be to indicate the location of the lights with respect to the symbol such as “north-south” when the light is incident from above and below the natural “top” and “bottom” of a symbol. The orientation of a symbol is known after decoding and related to the normal orientation of a symbol as specified in its symbology specification (e.g. a Data Matrix symbol’s natural orientation has the solid borders on left and bottom, and for QR Code, the normal orientation has finder patterns in the upper left, lower left and upper right corners but not lower right corner).

6.2.6 One direction (“S”)

Light is aimed at the part at the given angle ±3° from one side. The light may be incident from any of the four possible orientations with respect to the symbol. The plane perpendicular to the symbol surface containing the centre of the beam is aligned to be parallel to the line formed by one edge of the image sensor to within ±5°. The lighting shall illuminate the entire symbol area with nominally uniform energy. The angle specifier shall be “S” preceded by a number specifying the angle in degrees.

EXAMPLE “45S” (angle equal to 45°) or “30S” (angle equal to 30°).

Since there are four possible orientations in this setup, the particular orientation of the incident illumination should be reported based on the symbol orientation determined after decoding, with respect to the symbol’s normal orientation (see 6.2.5). For example, if a symbol is upside down, and the illumination is incident from below the symbol, such that the illumination is actually oriented toward the “top” of the symbol, then the incident light should be reported as “North”.

6.2.7 TCL setup

TCL setup uses coaxial light at the camera reading angle. Light is aimed at the camera reading angle with a tolerance of ±3°. The lighting shall illuminate the entire symbol area with nominally uniform energy.

In practice, the condition "coaxial lighting" can be implemented by an approximate setup like a high distance ring. The light angle tolerance of ±3° shall be respected.

Typical lighting setups are 30°, 45° or 60°. The angle specifier shall be “CS" preceded by a number specifying the angle in degrees. “CS” means coaxial “C” plus one direction “S”.

EXAMPLE “45CS” (angle equal to 45°) or “30CS” (angle equal to 30°).

NOTE A camera angle of 90° is not a TCL setup (not tilted). In consequence, a specification of "90CS" is not allowed.

6.3 Image focus

The camera is adjusted such that the symbol is in best focus.

6.4 Depth of field

Non-planar surfaces or a TCL setup can require a depth of field range. The condition given in ISO/IEC 15415:2024, 5.6.3 should be fulfilled for the whole depth of field range.

6.5 System response adjustment and reflectance calibration

System response recording is a task performed prior to the use of an instrument. It shall be repeated in regular intervals together with the regular adjustment of an instrument.

Capture an image of the reference symbol (test code on a calibration card, see 3.1). On such a card, a symbol which achieves a symbol contrast (see ISO/IEC 15415) grade of 4,0 shall be used. Using an aperture size of 80 % in relation to the test code module size, sample the centre of every element in the symbol including the quiet zone and set the system response so that the mean of the light elements is in the range of 70 % to 86 %, nominally 78 %, of the maximum grey scale, and the black level (no light) is nominally equal to zero. The system response is the nominally linear relationship between the reflectivity of the target and the pixel intensity values in the image as a result of several factors (e.g. shutter speed, imager sensitivity, f-stop, gain, illumination intensity). This procedure requires the ability to adjust at least one of these factors in order to adjust the system response.

Record the system response as the reference system response (S_{Rcal}) and record M_{Lcal}.

NOTE This procedure is not used for lighting configuration “90”.

7 Verifying a symbol

7.1 Initial image reflectance

7.1.1 General

The reference grey scale image is created by the following steps.

7.1.2 Initializing the aperture size

The minimum and maximum X-dimensions should be specified by the application specification and used by the verifier in this and subsequent steps. Set the aperture to 0,5 of the minimum X-dimension of the application and apply it to the image to create a reference grey scale image.

7.1.3 Creating an initial histogram

Create a histogram of the reference grey scale pixel values in a circular area 20 times the aperture size in diameter, centred on the image centre, and find the threshold, T_1, using the algorithm defined in Annex A.

The threshold divides the histogram into two portions: a portion below the threshold which contains dark pixels and a portion above the threshold which contains light pixels (called the “light lobe”).

NOTE If the circular area of 20 times of the aperture size is larger than the field of view of a real device, then the area is limited by the field of view.

7.1.4 Computing the mean

Compute the mean of the light lobe.

7.1.5 Optimizing an image

Adjust the system response by taking new images and repeating 7.1.2 and 7.1.3 until the mean of the light elements is 78 % reflectance of the maximum grey scale. A tolerance of ±8 % is acceptable for the mean value of the light elements. This results in a range from 70 % to 86 % for system response.

7.2 Obtaining the test image

7.2.1 Matrix symbologies

Matrix symbologies are specified in different appearances. Some are specified to consist of separate, unconnected dots. The reference decode of such symbologies takes care of handling these separated dots. Other symbologies are specified to consist of continuous connected matrix cells. Some marking technologies are not capable of producing such symbols with smooth, continuous lines. Therefore, they appear also with unconnected dots (e.g. if marked by a dot peen process). In this specific case, the code image is pre-processed to connect the unconnected dots; the algorithm given in Annex C shall be applied. After this pre-process, the standard reference decode algorithm is applied.

Once the grid of the symbol is determined, the location information is transferred to the evaluation of the reference grey scale image and subsequent processing occurs using the reference grey scale image.

7.2.2 Binarizing the image

Compute a reference grey scale image using initially the aperture size as defined in 7.1.2 or modified by 7.3.2 (depending on iteration). Using T_1, binarize the entire image.

7.3 Applying a reference decode algorithm

7.3.1 General

Attempt to find and process the symbol using the symbology reference decode algorithm and initially the aperture size as defined in 7.1.2 or modified by 7.3.2 (depending on iteration).

If a symbol with disconnected dots is detected for which no dot reference decode algorithm exists, the dot connecting algorithm in Annex C shall be applied. On a successful attempt, go to 7.4.

Where a symbology has a reference decode algorithm that operates successfully on nominally disconnected modules (e.g. “dot” codes), the process of connecting modules is inappropriate. With these symbologies, if the application of the reference decode algorithm fails, go to 7.3.2 (not Annex C).

7.3.2 Repeating if necessary

If the decode attempt fails, increase the aperture size by 1/10th of the X dimension range allowed in the application and go to 7.2.1. Stop if the aperture size exceeds the largest X dimension.

7.3.3 Continuing until the end

Continue until the symbol is successfully decoded or all aperture sizes are tested. If the symbol is not decoded, the symbol grade is zero.

7.4 Final image adjustment

7.4.1 General

This procedure uses only the nominal centres of modules to create a highly bi-modal histogram of the symbol reflectance states.

7.4.2 Determining the grid-centre point reflectance with two apertures

Re-compute the reference grey scale image using two new aperture sizes equal to 0,5 and 0,8 of the measured average grid spacing. Perform the following calculations and grading for both apertures.

7.4.3 Creating a grid-centre point histogram

Create a histogram of the reference grey scale image pixel values at each intersection point of the grid determined from the decode and find T_2 applying the algorithm given in Annex A.

7.4.4 Measuring the mean light

Measure the mean light (M_L) of the grid-centre point histogram. If it is 78 % (reflectance) of the maximum grey scale (e.g. 255 for an 8-bit image), then retain the values for mean dark (M_D) and mean light. A tolerance of ±8 % is acceptable for the mean light reflectance value. This results in a range from 70 % to 86 % for mean light.

If not, adjust the system response and go to 7.4.2.

NOTE The measurement algorithm for mean light (M_L) and mean dark (M_D) is described in Annex A.

7.4.5 Recording parameters

Set M_{Ltarget} equal to mean light (M_L). Record the system response as S_{Rtarget}. Record the new T_2.

7.4.6 Creating binarized images for the symbology reference decode

If the dot connecting algorithm in Annex C is to be applied in this step, then set the stick size to the average grid spacing and apply the dot connecting algorithm using T_2 on the new reference grey scale image to create the final binarized image. Otherwise, binarize using T_2.

7.4.7 Decoding

Decode the final binary image using the steps of 7.3 through 7.4.7 using the symbology reference decode algorithm without applying the dot connecting algorithm.

If the dot connecting algorithm is applicable to the symbology, repeat the decode and the following steps with dot connecting algorithm applied.

The Data Matrix reference decode algorithm contains a process of searching for clock tracks and quiet zones using minimum and maximum values of transition counts, which thus shall be taken from these two different binarized images separately.

Recalculate T_2 using the grid centres of this decode.

8 Determining the contrast parameters

8.1 Initializing the aperture size

Calculate the following parameters using the T_2 value and grid centres of 7.4.7.

8.2 Calculating cell contrast

Calculate cell contrast using Formula (1), using the algorithm given in Annex A:

$$C_c = (M_{\text{Ltarget}} - M_D) \,/\, M_{\text{Ltarget}} \tag{1}$$

where C_c is the cell contrast value.

8.3 Calculating the cell module modulation

Calculate cell module modulation (CMOD) using Formula (2).

If $R < T_2$, then

$$C_{MOD} = (T_2 - R) / (T_2 - M_D)$$

Else

$$C_{MOD} = (R - T_2) / (M_{Ltarget} - T_2) \tag{2}$$

where

R is the measured reflectance of the cell;

C_{MOD} is the cell module modulation.

8.4 Calculating the minimum reflectance

Calculate the minimum reflectance (R_{target}) using Formula (3):

$$R_{target} = R_{cal} \times (S_{Rcal} / S_{Rtarget}) \times (M_{Ltarget} / M_{Lcal}) \tag{3}$$

When the lighting is "/90" (specular reflectance), S_{Rcal} and M_{Lcal} are not defined. See 9.2.

9 Grading

9.1 Cell contrast

The grade levels for cell contrast grading are given in Table 1.

Table 1 — Grade levels of cell contrast

CC	Grade
≥ 30 %	4,0
≥ 25 % and < 30 %	3,0 to 3,9
≥ 20 % and < 25 %	2,0 to 2,9
≥ 15 % and < 20 %	1,0 to 1,9
≥ 10 % and < 15 %	0,0 to 0,9
< 10 %	0,0

The grade shall be computed as a linearly interpolated value, rounded to the next lowest 0,1 (tenth) of a grade level.

For example, a cell contrast value of 21 % gets a grade of 2,2 and a cell contrast value of 13 % gets a grade of 0,6.

The grade may be evaluated from the cell contrast value using Formulae (4), (5) and (6):

if $C_c \geq 30$ %, the grade is 4,0 (4)

if 10 % < C_c < 30 %, the grade is rounddown10($(20 \times C_c) - 2$) (5)

if $C_c \leq 10$ %, the grade is 0,0 (6)

where C_c is the cell contrast.

The function "rounddown10()" rounds down the second digit after the point and may be defined as: rounddown10(x) := floor(x*10)/10

The function "floor(x)" rounds to the largest integer that does not exceed x as follows: floor(x) = $\lfloor x \rfloor$.

9.2 Minimum reflectance

The grade levels for minimum reflectance (R_{target}) grading are given in Table 2.

Table 2 — Grade levels of minimum reflectance

R_{target}	**Grade**
≥ 20 %	4,0
≥ 15 % and < 20 %	3,5 to 3,9
≥ 10 % and < 15 %	2,5 to 3,4
≥ 5 % and < 10 %	1,5 to 2,4
≥ 0 % and < 5 %	0,0 to 1,4

The grade shall be computed as a linearly interpolated value, rounded to the next lowest 0,1 (tenth) of a grade level.

For example, a R_{target} value of 13 % gets a grade of 3,1 and a R_{target} value of 3 % gets a grade of 0,9.

The continuous grade may be evaluated from the minimum reflectance value using Formulae (7), (8), (9), (10) and (11):

if $R_{target} \geq 20$, the grade is 4,0 (7)

if 15 % $\leq R_{target} < 20$, the grade is rounddown10(10 × R_{target} + 2) (8)

if 5 % $\leq R_{target} <$ 15 %, the grade is rounddown10(20 × R_{target} + 0,5) (9)

if 0 % $< R_{target} <$ 5 %, the grade is rounddown10(30 × R_{target}) (10)

if R_{target} = 0 %, the grade is 0,0 (11)

See 9.1 for a definition of the rounddown10() function.

When the lighting is "/90", R_{target} is not determined. R_{target} is then either not reported or reported as n/a (not applicable).

9.3 Cell modulation

The ISO/IEC 15415 modulation parameter is replaced with CM.

CM calculation follows the method for modulation of ISO/IEC 15415, with the following modifications.

— The value CMOD described in 8.3 is used instead of the ISO/IEC 15415 value MOD.

— The grade level for CMOD is identical to the grades given by the formula in ISO/IEC 15415 and set to 0 if the module is decoded as error.

9.4 Fixed pattern damage

Calculate fixed pattern damage (FPD) as described in ISO/IEC 15415 and the symbology specifications, except:

— use the threshold T_2 for the modulation overlay;

— when determining the distributed fixed pattern damage (DFPD) grade in accordance with ISO/IEC 16022 for Data Matrix, take the average of the notional grades at the 1,0 grade level;

— use the result of dot connecting algorithm for all features of the symbol that are defined to be continuous, such as solid borders and interior solid segments of Data Matrix finder pattern, but use the unconnected binarized image for features that are not normally continuous, such as clock tracks.

The Data Matrix reference decode algorithm contains a process of searching for clock tracks and quiet zones using minimum and maximum values of transition counts, which thus shall be taken from these two different binarized images separately.

The transition ratio test for Data Matrix shall correspondingly use these two separate binarized images.

9.5 Final grade

Select the best of the results obtained from the two different apertures as described in 7.4.2 and then the decode with and without the dot connecting algorithm (if applicable) and use the associated image and parameters for the remainder of the grading calculations from ISO/IEC 15415. If there are multiple best choices, select first the decode without the dot connecting algorithm and then the aperture size of 0,8 X.

10 Communicating grade requirements and results

10.1 General

Clause 10 discusses the method of signalling grading requirements to the maker of the mark and for reporting the resulting grade to the customer. Depending on the requirements of the application specification, one or more grades for each part may be required. See Annex D.

10.2 Communication of application requirements

The application shall specify a range of X-dimensions (in mils, a unit of measure equal to one thousandth of an inch), taking into consideration that large X-dimensions will facilitate greater surface texture. For example, for an application that has a range of X of 10 mils to 20 mils, the grade requirement is communicated as /10-20/ in place of the aperture size.

The application shall specify the minimum accepting passing grade.

Lighting requirements are communicated as described in 6.2.

The following multiple lighting options may be used: lighting is specified using the separator "|" to designate "or" and the separator "&" to designate "and". Each lighting option is measured independently.

EXAMPLE 1 (30Q|90): the application allows “30Q” or “90” lighting to fulfil the requirement.

EXAMPLE 2 (30Q&90): the application requires two verifications to pass, one measured with “30Q” and the other with “90” lighting.

The lighting angle is reported as the single angle that was used to determine the grade. If the requirement is for more than one angle, then at least the lowest grade shall be reported or optionally one grade reported for each angle.

EXAMPLE 3 A specification of the acceptance criteria of DPM 2,0/05-10/660/(45Q&90) means that each verification has to pass with a 2,0 grade or better with each of the specified lightings and the symbol X dimension range has to be between 0,125 mm and 0,25 mm.

EXAMPLE 4 A specification of DPM 2,0/05-10/660/(45Q | 90) means that either a verification with “90” or with “45Q” has to pass but not necessarily both.

10.3 Communicating from verifier to application

Grades reported according to this document shall be prefaced with "DPM". With the preface of "DPM", the grade, aperture size and light colour are reported in the same way as defined in ISO/IEC 15415, however lighting angle and orientation are communicated as described in 6.2.

The verifier report shall indicate whether the result was obtained with or without the use of the dot connecting algorithm.

10.4 Communicating the use of a proprietary decode

When a proprietary decode is used, the rest of the metrics shall follow the requirements of this document.

When a proprietary decode is used, it shall be clearly reported in the grade report. For example, the verifier shall report a grade of 0 (zero) for decode and may report the other measurements of this document.

When a proprietary decode is allowed, it shall be clearly stated in the application specification.

NOTE When a proprietary decode is used, the sampling points for the remaining metrics can differ from verifier to verifier.

Annex A
(normative)

Threshold determination method

A.1 Algorithm description

Start by creating a histogram of the defined grey scale values in the defined region and proceed as follows.

a) Initialize the variable V_{min} to a very large number and initialize T_{min} and T_{max} to zero.

b) For every grey scale value, "g", starting from the lowest grey scale value to the highest grey scale value (0 to 255 for an 8-bit image sensor).

1) Compute the mean and variance of pixels below g and call it M_D (mean dark) and V_D (dark variance).

2) Compute the mean and variance of pixels above or equal to g and call it M_L (mean light) and V_L (light variance).

3) Compute the variance: $V = V_L + V_D$.

4) If $V < V_{min}$, save V in V_{min} and save g in T_{min}.

5) If $V = V_{min}$ save g in T_{max}.

NOTE b) 5) is used to break ties. T_{min} is the smallest grey-level where the variance is the minimum and T_{max} is the largest grey-level where the variance is the same minimum.

c) The optimal threshold is: $T = (T_{min} + T_{max}) / 2$.

A.2 Example

For simplicity, an image with only 100 pixels (a 10 × 10 image) is used. Additionally, for the purpose of the example, the image is composed of 4-bit pixels (16 grey levels). The sample image is shown in Figure A.1, where each pixel is magnified so that individual pixels can be discerned.

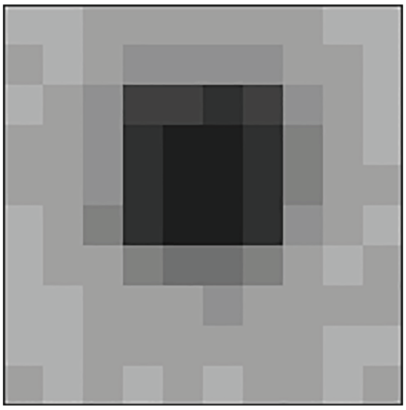


Figure A.1 — Image used in this example

Begin by counting how many pixels are contained in the image with each of the 16 grey levels. The result of this count is shown in Table A.1 and is plotted as a histogram in Figure A.2.

Table A.1 — Count of grey level occurrences

Grey level	Number of pixels with grey level
0	0
1	0
2	6
3	7
4	3
5	0
6	0
7	2
8	5
9	10
10	44
11	23
12	0
13	0
14	0
15	0

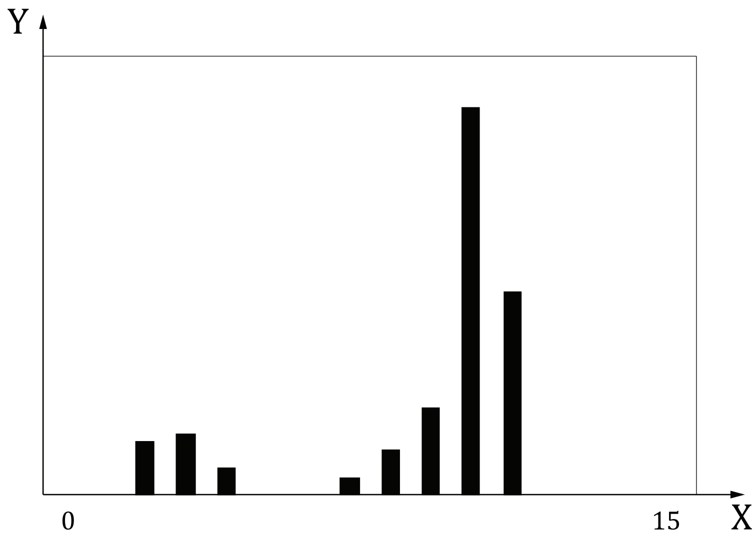


Figure A.2 — Histogram of the data from Table A.1

For each possible threshold, the histogram is separated into two portions – one for the dark elements and one for the light elements. The first possible threshold is between 0 and 1, the next is between 1 and 2, and so on. For each possible threshold, compute the variance of both portions of the histogram.

For example, for the possible threshold between 4 and 5, the dark element histogram contains the grey levels 0, 1, 2, 3 and 4 as shown in Table A.2.

Table A.2 — Dark pixel portion for threshold of 4,5

Grey level	Number of pixels with grey level
0	0
1	0
2	6
3	7
4	3

The variance of this distribution is calculated as follows.

The mean is $((2 \times 6) + (3 \times 7) + (4 \times 3)) \div 16 = 2{,}81$, which can be described as the weighted average of Table A.2.

The variance is the average of the square of each element's deviation from the mean:

$$(((2{,}81 - 2)^2 \times 6) + ((2{,}81 - 3)^2 \times 7) + ((2{,}81 - 4)^2 \times 3)) \div 16 = 0{,}53$$

Similarly, the variance of the light elements (those whose pixel value is 5 or greater) is 0,84.

Likewise, the variances of the dark and light portions of the histogram for each threshold can be computed. The results are shown in Table A.3.

Table A.3 — List of variances for all possible thresholds

Threshold	Variance of dark elements	Variance of light elements	Sum of variances
0,5	0,00	7,67	7,67
1,5	0,00	7,67	7,67
2,5	0,00	5,00	5,00
3,5	0,25	2,00	2,25
4,5	0,53	0,84	1,37
5,5	0,53	0,84	1,37
6,5	0,53	0,84	1,37
7,5	2,20	0,65	2,85
8,5	5,52	0,40	5,92
9,5	8,50	0,23	8,73
10,5	8,11	0,00	8,11
11,5	7,67	0,00	7,67
12,5	7,67	0,00	7,67
13,5	7,67	0,00	7,67
14,5	7,67	0,00	7,67
15,5	7,67	0,00	7,67

An optimum threshold is chosen such that the sum of variances of both portions of the histogram is minimized. As can be seen from Table A.3, the minimum of the sum of variances is 1,37 which occurs at thresholds 4,5, 5,5 and 6,5. There is a range of thresholds that all give this minimum variance. In this case, take the average of the lowest and highest threshold which give this minimum, which is 5,5 in this example.

Note that the threshold obtained by this averaging will not necessarily have the same minimum sum of variances as it does in this example. If there is a single threshold which gives the minimum sum of variances, then take that threshold. This chosen threshold is considered the “optimum” threshold as determined by the algorithm in Clause A.1, because it results in two separate portions of the overall histogram, which are assumed to be most representative of two groups of elements (dark and light).

NOTE The portion of the histogram to the right of the threshold is called the “light lobe”.

When the image is binarized using the calculated threshold, the result is shown as in Figure A.3.

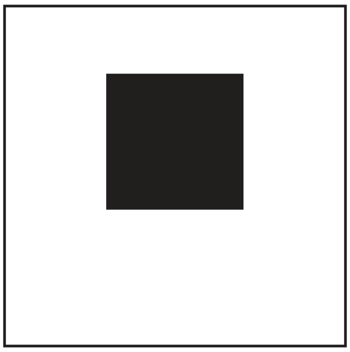


Figure A.3 — Image with threshold applied

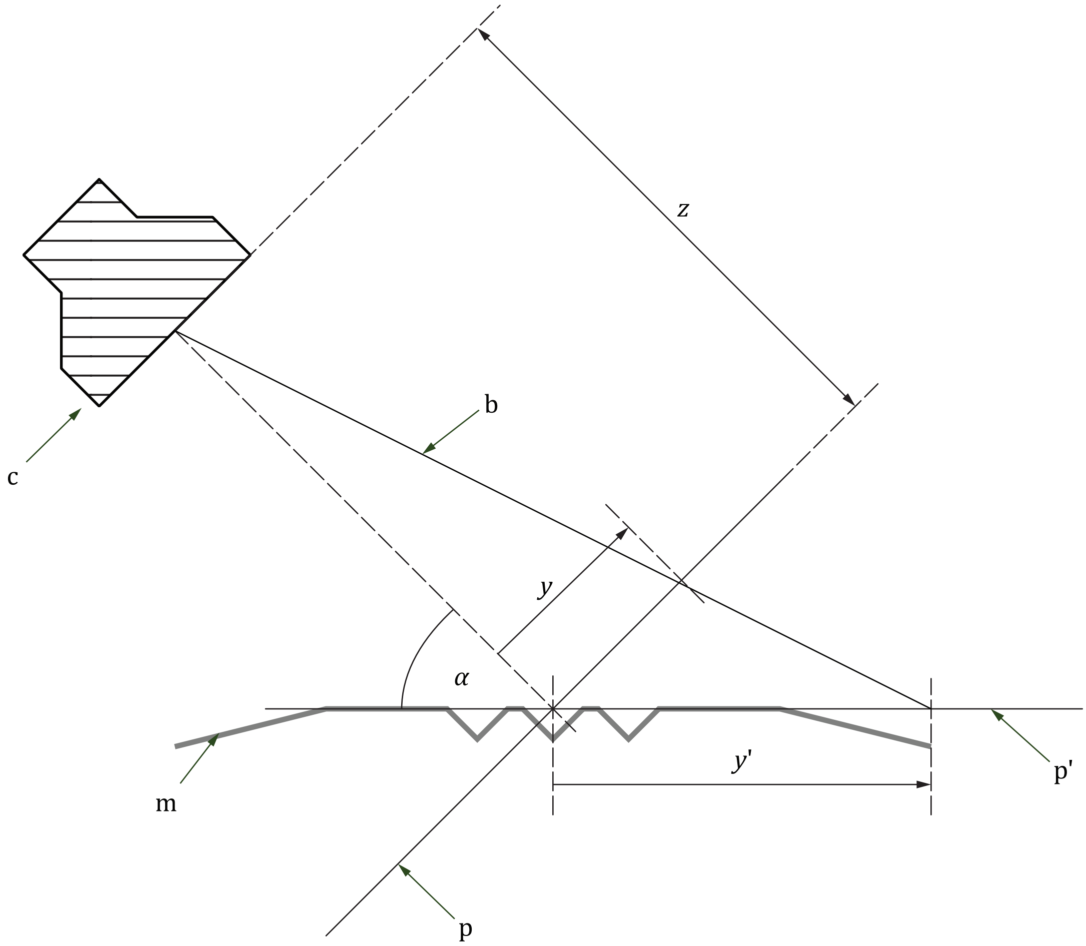
Annex B
(informative)

Evaluation of image at virtual 90° camera position from real tilted camera position

B.1 General

Within TCL setup, the camera position is tilted by the camera reading angle. This annex describes the evaluation of an image with a virtual camera reading angle of 90°.

Figure B.1 shows a side view of the set up. The third dimension (*x*) is not shown.



Key

c	camera	p′	virtual camera image plane for a virtual camera at 90° camera reading angle
m	marked object	b	example light beam connecting example point *y* on the image camera plane (p) and point *y*′ on the virtual camera image plane (p′)
α	camera reading angle		
z	camera distance	*y*	*y* position of the sample point on the camera image plane (p)
p	camera image plane	*y*′	*y* position of the sample point on the virtual camera plane (p′)

Figure B.1 — Relation of the camera image plane and the virtual camera image plane (side view)

The coordinate system of the camera image plane is defined by x (into the drawing plane) and y (tilted axis). The coordinate system of the virtual camera image plane of the virtual camera position of 90° is defined by x' (into the drawing) and y' (horizontal axis). Both coordinate systems join their zero points horizontally on the camera plane.

B.2 Algorithm

The task is to evaluate the virtual image on plane p′ from the image on the camera plane p. Each plane consists of grey level values

The following two-step procedure is performed for each point on the virtual image plane (e.g. for each possible x', y' value).

a) The position of the point of plane p is evaluated with floating point resolution.

b) The value of the image point is evaluated by linear interpolation from the values of plane p.

The two steps are described in the following clauses.

B.3 Evaluation of the point x', y' on the camera image plane p

Images are organized as pixels on positive integer positions. In a first step, the position of each virtual image pixel on the virtual plane x_p, y_p is evaluated by scaling by the resolution and translation to the zero point of the coordinate system.

Then, the position on p′ of a given point on plane p may be evaluated using Formulae (B.1) and (B.2):

$$x = x' \frac{1}{1 + y' \frac{\cos\alpha}{z}} \tag{B.1}$$

$$y = y' \frac{\sin\alpha}{1 + y' \frac{\cos\alpha}{z}} \tag{B.2}$$

where

- x' is the x position on the virtual camera plane (p′);
- y' is the y position on the virtual camera plane (p′);
- x is the x position on the camera image plane (p);
- y is the y position on the camera image plane (p);
- α is the camera reading angle;
- z is the camera distance.

After this evaluation, the resulting floating point location is scaled and translated to the pixel position of the camera pane p. The result is not rounded to an integer position resulting in an intermediate position on the pixel plane.

EXAMPLE The pixel plane on the virtual plane is 2 000 × 2 000 pixels in size. The 0-point is centred at position 1 000/1 000. The physical resolution is 400 pixel/mm.

The example point is located at pixel position x_p = 1 400, y_p = 1 600 on the virtual pane. Its physical location is evaluated as:

x' = (1 400 − 1 000)/400 = 1 mm

y' = (1 600 − 1 000)/400 = 1,5 mm

The camera reading angle is 60° (radian: π/3) and the distance is 100 mm. The resulting x and y values are x = 0,992 6 mm and y = 1,289 mm.

This physical position is now translated to the pixel pane of the physical camera position pane. The pixel pane has a size of 3 000 × 3 000 pixels. The 0 point is centred at position 1 500/1 500. The physical resolution is 600 pixel/mm.

The example pixel positions are:

x'_p=0,992 6 mm * 600/mm + 1 500 = 2 095,53

y'_p = 1,289 mm * 600/mm + 1 500 = 2 273,62

B.4 Evaluation of the value of the point x', y' by linear interpolation

The value of the point is evaluated by linear interpolation from the surrounding 4 pixels.

The 4 surrounding pixels of the physical image plane are located at the integer positions around the floating point pixel position. The values of the pixels are named v_{00}, v_{01}, v_{10} and v_{11}, with the first subscript indicating the column and the second subscript indicating the row.

The remaining distance fraction (from 0,0 to not including 1,0) is called f_x and f_y.

The pixel value for pixel x_p, y_p is evaluated as:

$$(v_{00} * (1 - f_x) + v_{10} * f_x) * (1 - f_y) + (v_{01} * (1 - f_x) + v_{11} * f_x) * f_y$$

EXAMPLE The example floating point position is at 2 095,53/2 273,62.

The surrounding pixels are located at v_{00} (2 095/2 273), v_{10} (2 096/2 273), v_{01} (2 095/2 274) and v_{11} (2 096/2 274). In this example, the following values are used: v_{00} = 50, v_{01} = 80, v_{10} = 70 and v_{11} = 90

The remaining distance fractions are f_x = 0,53 and f_y = 0,62.

The resulting value for the pixel at 1 400/1 300 is evaluated as:

(50 * (1 − 0,53) + 70 * 0,53) * (1 − 0,62) + (80 * (1 − 0,53) + 90 * 0,53) * 0,62

= (50 * 0,47 + 70 * 0,53) * 0,38 + (80 * 0,47 + 90 * 0,53) * 0,62

= 75,914

Annex C
(normative)

Dot connecting algorithm

C.1 General

This process is called the "stick function" and operates on the binarized image. The output is used for the initial decode using the reference decode algorithm. The steps below seek to connect areas in the image that are separated by less than one module, while not connecting areas which are separated by a distance of a module or more, for example alternating dark and light single modules (known as the clock track).

C.2 Initializing stick size and module colour

Since a module size is not known during the execution of this algorithm, successively larger distance guesses are used within a range from the size of 50 % of the smallest X-dimension to 110 % of the largest X-dimension allowed by the application specification.

In addition, knowledge of the colour of “on” versus “off” modules is also required by the algorithm. Generally, the “on” colour is dark for bright field illumination and light for dark field illumination. (For instance, the "on" colour is the colour of the “L” pattern of a Data Matrix symbol.) If a verifier does not “know” the colour of "on", the algorithm can be required to be repeated for each case.

NOTE Implementers are free to optimize this algorithm (such as by attempting a better first guess of the correct stick size by analyzing the image) as long as the equivalent result is obtained.

C.3 Connecting pixels

The dot connecting algorithm finds nearby pixels of the same reflectance state (i.e. light or dark) and connects them.

a) Prepare by:

   1) setting every pixel in the output image to the background (off) colour;

   2) selecting an initial stick size equal to 50 % of the minimum X dimension of the application.

b) Starting on the row of the image one half-stick length down from the top and the column one half-stick length in from the left:

   1) If the colour of the pixel is the “on” colour, set the pixel in the same position in the output image to the “on” colour, and continue at b) 5).

   2) Find the two pixels which are one-half stick distance to the left and one-half the stick distance to the right and the two pixels that are one-half stick distance above and below.

   3) If both of the horizontal or vertical pixels found in b) 2) are the “on” colour, then go to b) 4); otherwise continue to b) 5).

   4) For each pixel on the line or lines between the two "on" pixels found in b) 2) (a line equal in length to the stick), set the correspondingly positioned pixels in the output image to the “on” colour.

   5) Move to the next pixel and go to b) 1). (If the position of the current pixel is one half-stick length in from the right, the next pixel is at the start of the column one half-stick length in from the left of the

next row. If the position of the current pixel is on the row one half stick length up from the bottom, and one half stick length in from the right, exit since the image is completely processed.)

C.4 Applying the reference decode algorithm

C.4.1 General

The referenced matrix symbologies all require finding the locating of continuous modules in their reference decode algorithms. Some marking technologies are not capable of producing symbols with smooth, continuous lines when viewed by an imager. For example, dot peened symbols often produce unconnected dots.

Once the primary lines of the symbol have been determined, that location information is transferred to the original image and subsequent processing occurs.

C.4.2 Finding symbology reference lines

Using the connected image from Clause C.2, find the symbology reference lines with the symbology reference decode algorithm.

EXAMPLE The symbology reference lines for Data Matrix comprise the "L" finder pattern.

C.4.3 Transferring reference lines

Transfer the reference lines to the original binarized image. Perform the rest of the reference decode algorithm. If successful, go to 7.4.

C.5 Repeating if necessary

If the decode attempt fails, choose a new stick size that is at least one pixel more in length and a new aperture size equal to 0,8 stick size and go to 7.2.1.

C.6 Continuing until end

Continue until the symbol is successfully decoded or the stick size exceeds the maximum stick size or one-tenth of the maximum image dimension in pixels (if the maximum X-dimension is not known). If the lines are not found, the symbol grade is zero.

NOTE This algorithm assumes that the symbol is oriented orthogonal to the image sensor, so that modules that have to be connected are aligned vertically and horizontally in the image. If this were not true, the stick would need to be rotated through all angles, in addition to the vertical and horizontal directions.

Annex D
(informative)

Communicating the grade

D.1 General

This annex describes a potential method of communication between the creator of the mark and the user of the mark. It is not intended to be a quantitative requirement. An application may specify different requirements or descriptions depending on the anticipated scanning environments.

D.2 Scanning environment examples

D.2.1 Category 0 part description

The most stringent marking environment requires that a mark be easy to read in "normal" (diffuse reflection off printed labels) scanning environments where scanners are not expected to be able to read most DPM parts. This requirement is not prefaced with "DPM" and follows procedures laid out in ISO/IEC 15415 and the symbology specification. This type of requirement is referred to as "Category 0" and is the default if the requirement is not prefaced with "DPM".

D.2.2 Category 1 part description

Parts that are easy to read using a specialized DPM type scanner in a field type environment, such as a supply depot or an airfield which also may include printed labels. This type of requirement is referred to as "Category 1". Category 1 parts can require some user orientation of the DPM scanner.

D.2.3 Category 2 part description

Parts that require specialized lighting to be read, such as those with curved surfaces, very low contrast or highly textured surfaces. Such parts should not be expected to be read in field type situations, but are intended to be read in specialized environments, such as a sophisticated repair location. This type of requirement is referred to as "Category 2".

D.2.4 Category 3 part description

Parts which cannot pass this specification and that have marking methods and substrates that cannot be modified to pass, including some parts with difficult surface conditions for use in extreme environments and/or parts with difficult lighting access to the symbol. These parts can require not only specialized lighting but also proprietary reading devices. These parts cannot be expected to be read in open system environments.

Category 3 parts should be evaluated using proprietary algorithms to determine decode, unused error correction, grid non-uniformity and axial non-uniformity and/or by using a visual based method such as the one for Data Matrix described in SAE AS9132[2].

D.3 Grade communication examples

D.3.1 General

The following are reasonable examples of grading communication both from an application specification to the maker of the mark and for reporting the resulting grade to the customer.

The light colour shown in these examples is typical of current commercially-available scanners. The application is free to choose any light colour appropriate for its scanning environment.

For requirement examples, a single number is used but it conveys the tolerance specified in the application specification.

A typical range of light sources is 635 nm to 660 nm. The examples below use a single wavelength of 640 nm for convenience and does not represent a recommendation for any specific application.

D.3.2 Grade requirement examples

D.3.2.1 Category 0 part requirement

2,0/05/640

This requirement is typical in a printed label environment where DPM parts are not encountered. In this instance, lighting is “45Q” and there is no DPM processing. The grade specification and processing follow ISO/IEC 15415.

D.3.2.2 Category 1 part requirement

DPM2,0/10-20/640/(30Q|90)

This requirement is intended for mixed environments where both printed labels and DPM parts are encountered and where the DPM parts are relatively easy to read with a DPM scanner and a moderately trained operator.

A passing grade greater of 2,0 of either “30Q” or “90” lighting is acceptable.

D.3.2.3 Category 2 part requirement

DPM1,0/10-20/640/(30Q|90|30T|D)

This requirement is intended for DPM environments where parts are both difficult to mark and/or where the parts are intended to be read using specialized lighting, fixed mount operation and/or extensive user training.

NOTE The "10-20" corresponds to the X-dimension range of the application, not the aperture size.

A passing grade of 1,0 of one of the lightings “30Q”, “90”, “30T”, “D” is acceptable.

D.3.2.4 Category 2 part requirement with TCL setup

DPM1,0/10-12/640/60CS

This requirement is for a dot peen mark marked with a pin of 120° pin angle (2 × 60°). It should be read at a coaxial camera angle of 60°.

The module size (which is more a grid size in this application) is within the short range of 10 mils to 12 mils.

D.3.3 Grade reporting examples

D.3.3.1 Category 0 part reporting (following ISO/IEC 15415)

2,0/05/640

is acceptable even if the other grades are less than 2,0.

D.3.3.2 Category 1 part reporting

One of either

DPM2,0/08/640/30Q

or

DPM2,0/16/640/90

is acceptable even if the other grades are less than 2,0.

D.3.3.3 Category 2 part reporting

One of either

DPM1,0/08/640/30T

or

DPM1,0/16/640/90

or

DPM1,0/05/640/D

is acceptable even if one or more of the other grades is less than 1,0.

NOTE The single value, i.e. "16", refers to the size of the aperture used to obtain the grade for the symbol, not the X-dimension of the symbol.

D.3.4 Application grade reporting

D.3.4.1 General

The application specification is the place where the technology meets the marking vendor. A simple communication method is suggested in application specifications using a green/yellow/red format for use by the marking vendor. Following are suggested outputs for the examples in Clause D.3.

D.3.4.2 Category 0 part reporting

Green	3 or better
Yellow	2 or better but less than 3
Red	less than 2

D.3.4.3 Category 1 part reporting

Green	3 or better
Yellow	2 or better but less than 3
Red	less than 2

D.3.4.4 Category 2 part reporting

Green	2 or better
Yellow	1 or better but less than 2
Red	less than 1

Annex E
(informative)

Cross-reference comparison to ISO/IEC 15415

(Sub)clause of ISO/IEC 15415:2024	(Sub)clause of this document	Description of changes made to this document compared to ISO/IEC 15415:2024
5.6.1 General requirements	Clauses 6 and 7	100 % reflectance has been defined for specular reflection.
5.6.3 Geometry of the optical setup	6.2.1, 6.2.3, 6.2.5	Dome and two-sided illumination environments have been added.
7.4 Grading procedure	Clause 7	"Dot Connecting Algorithm" algorithm has been added between the steps of binarized image and performing the initial decode.
7.5.4 Symbol contrast	9.1	SC has been replaced with CC.
7.5.5.1 Modulation	9.3	Modulation has been replaced with CMOD, using a new calculation for threshold and a formula for CMOD.
7.5.6 Fixed pattern damage	9.4	A new calculation of threshold has been added for "modulation overlay".

Bibliography

[1] ISO/IEC 16022, *Information technology — Automatic identification and data capture techniques — Data Matrix bar code symbology specification*

[2] SAE International, AS9132: Data Matrix (2d) Coding Quality Requirements for Parts Marking, 2017

[3] ISO/IEC 18004, *Information technology — Automatic identification and data capture techniques — QR Code bar code symbology specification*

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