INTERNATIONAL STANDARD

ISO/IEC 30116

First edition
2016-10-01

Information technology — Automatic identification and data capture techniques — Optical Character Recognition (OCR) quality testing

Technologies de l'information — Techniques automatiques d'identification et de capture des données — Essais de qualité des caractères pour reconnaissance optique

Contents

Page

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC 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 on 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 the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/JTC 1, *Information technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

Introduction

For the inspection of ID documents, i.e. MRTDs (Machine Readable Travel Documents) according to ISO/IEC 7501 (all parts)/ICAO Doc 9303 (all parts) and driving licences according to ISO/IEC 18013 (all parts), a reliable and ergonomic document inspection technology is essential. Considering RFID interoperability, strong improvement has been reached introducing mechanisms for interoperability evaluation and testing of MRTDs and reader devices. Similar standards for optical reading would improve the reliability of OCR. This is especially important because OCR of the document's MRZ (Machine Readable Zone) is essential for accessing BAC (Basic Access Control) and/or SAC (Supplementary Access Control) protected passports.

Thus, reliable OCR makes the performance of automated border control systems, as well as of many other applications, more predictable. Furthermore, the evaluation of document reader products can be done much easier. This standardization project defines test methods to evaluate OCR document quality. Furthermore, it defines requirements ensuring the compliance to the applicable OCR standards. The project applies experiences from other domains such as bar code reading and possibly other test methods for OCR. Where conflicts in the specification work between MRTDs and driving licenses may arise, satisfying the definitions for MRTDs is given preference.

Information technology — Automatic identification and data capture techniques — Optical Character Recognition (OCR) quality testing

1 Scope

This document

— specifies the methodology for the measurement of specific attributes of OCR-B character strings,

— defines a method for evaluating these measurements and deriving an overall assessment of character string quality,

— defines a reference decode algorithm for OCR-B, and

— gives information on possible causes of deviation from optimum grades to assist users in taking appropriate corrective action.

This document applies to OCR-B as defined in ISO 1073-2, but its methodology can be applied partially or wholly to other OCR fonts.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

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

3.1
binarized image
binary (black/white) image created by applying the global threshold to the *pixel* (3.5) values in the reference grey-scale image

3.2
document reference edge
physical (i.e. mechanical) end of the surface with the MRZ whose position is determined by putting a black background under the surface with the MRZ and sliding the document up against a physical stop

3.3
inspection area
rectangular area which contains the entire *symbol* (3.11) to be tested inclusive of its quiet zones

3.4
character outline limits
outlines of an ideal printed image of a character

Note 1 to entry: This is a qualitative evaluation utilized in ISO 1831 that is replaced in this document with SWT.

3.5
pixel
individual light-sensitive element in a light-sensitive array

Note 1 to entry: Examples of light-sensitive array are CCD (charge coupled device) or CMOS (complementary metal oxide semiconductor) device.

3.6
raw image
matrix of the reflectance values in x and y coordinates across a two-dimensional image, derived from the discrete reflectance values of each *pixel* (3.5) of the light-sensitive array

3.7
reference grey-scale image
raw image (3.6) convolved with a synthesized circular aperture

3.8
scan grade
result of the assessment of a single scan of an OCR symbol, derived by taking the lowest grade achieved for any measured parameter of the reference grey-scale and *binarized images* (3.1)

3.9
stroke width
nominal dimension perpendicular to the direction of the line making up an OCR character

3.10
stroke width template
inner and outer character boundaries defined by circles whose centres follow the line created by the character centreline coordinates defined in Annex A

3.11
symbol
group of OCR characters comprising the entire machine-readable entity (e.g. Machine Readable Zone (MRZ) as specified in ICAO 9303, sizes ID-1, ID-2 and ID-3) including quiet zones and the *document reference edge* (3.2)

Note 1 to entry: Document sizes are defined in ISO/IEC 7501 (all parts) (ICAO 9303) as TD1, TD2 and TD2, whereas the same sizes are defined in ISO/IEC 7810 as ID-1, ID-1 and ID-3. In this document, we use the terms ID-1, ID-2 and ID-3.

3.12
X-tolerance
0,08 mm for Size I with a nominal *stroke width* (3.9) of 0,35 mm

Note 1 to entry: 0,08 mm for Size I with a nominal stroke width of 0,35 mm was originally defined in ISO 1831:1980, Table 2.

3.13
Y-tolerance
0,15 mm for Size I with a nominal *stroke width* (3.9) of 0,35 mm

Note 1 to entry: 0,15 mm for Size I with a nominal stroke width of 0,35 mm was originally defined in ISO 1831:1980, Table 2.

4 Abbreviated terms

COL   character outline limits

CEV   character evaluation value

MRZ   machine readable zone

SWT   stroke width template

5 Quality grading

Quality grades for best-fit, PCS, position and background noise are determined as one of three levels: recommended, needs attention and not recommended. The parameter with the lowest grade is the grade of the symbol.

6 Measurement methodology for OCR-B

6.1 Overview of methodology

The basis of the measurement methodology is the evaluation of reflectance from the symbol. This methodology is also intended to correlate with conditions encountered in OCR scanning systems. The method starts by obtaining the raw image, which is a high-resolution grey-scale image of the symbol captured under controlled illumination and viewing conditions.

6.2 Obtaining the test image

6.2.1 Measurement conditions

A test image of the symbol shall be obtained in a configuration that mimics the typical scanning situation for that symbol, but with substantially higher resolution (see 6.3.3), uniform illumination and at best focus. The reference optical arrangement is defined in 6.3.4. Alternative optical arrangements may be used provided that the measurements obtained with them can be correlated with the use of the reference optical arrangement.

Ambient light levels shall be controlled in order not to influence the measurement results. Whenever possible, measurements shall be made on the symbol in its final configuration, i.e. the configuration in which it is intended to be scanned. For MRTD evaluation, optically personalized samples shall be used. This includes that all layers available at a document including laminations, security features and protective layers shall be present.

Two principles govern the design of the optical set-up. First, the test image's grey-scale shall be nominally linear and not be enhanced in any way. Second, the image resolution shall be adequate to produce consistent readings, which generally requires that the character stroke-widths span at least 10 image pixels.

6.2.2 Raw image

The raw image is a matrix of the actual reflectance values for each pixel of the light-sensitive array, from which are derived the reference grey-scale image and the binarized image which are evaluated for the assessment of symbol quality.

6.2.3 Reference grey-scale image

The reference grey-scale image is obtained from the raw image by processing the individual pixel reflectance values through a synthetic circular aperture equal to 0,2 mm.

      3

6.2.4 Binarized image

The binarized image is obtained from the reference grey-scale image by applying the algorithm defined in Annex B.

6.3 Reference reflectivity measurements

6.3.1 General requirements

Equipment for assessing the quality of symbols in accordance with this subclause shall comprise a means of measuring and analysing the variations in the reflectivity of a symbol on its substrate over an inspection area which shall cover the full height and width of the symbol.

The measured reflectance values shall be expressed in percentage terms by means of calibration and reference to recognized national standards laboratories, where 100 per cent should correspond to the reflectance of a barium sulphate or magnesium oxide reference sample.

It should be ensured that all materials visible to the camera or close to the optical path are reflection-free, at least in IR illumination. In particular, the background the symbol is attached to shall be IR absorbing. The environment temperature shall be between 20°C and 25°C.

6.3.2 Light sources

Measurements shall be made using light emitting diode (LED) light sources at 890 nm and 940 nm wavelengths.

All illumination elements shall have a diameter of 25 mm or less and may be shaped as circles, squares or similar.

6.3.3 Effective resolution

The effective resolution of an instrument that implements this document shall be sufficient to ensure that the parameter grading results are consistent irrespective of the rotation of the symbol. The effective resolution is the product of the resolution of the light-sensitive array and of the magnification of the associated optical system and effected by distortions introduced by the optical system. The reference optical arrangement requires an effective resolution of not less than 10 pixels per stroke width.

6.3.4 Optical geometry

A reference optical geometry is defined for reflectivity measurements and consists of

— flood incident illumination, uniform across the inspection area, from a set of four light sources arranged at 90-degree intervals around a circle concentric with the inspection area and in a plane parallel to that of the inspection area, at a height which will allow incident light to fall on the centre of the inspection area at an angle of 45° to its plane, and

— a light collection device, the optical axis of which is perpendicular to the inspection area and passes through its centre, and which focuses an image of the test symbol on a light-sensitive array.

The light reflected from the inspection area shall be collected and focused on the light-sensitive array.

Implementations may use alternative optical geometries and components, provided that their performance can be correlated with that of the reference optical arrangement defined in this subclause. Figure 1 and Figure 2 illustrate the principle of the optical arrangement, but are not intended to represent actual devices; in particular, the magnification of the device is likely to differ from 1:1. For example, it is possible to use a 10 MP industrial camera without IR cut filter with a sensor size of ½". The image could be captured from a distance of approximately 350 mm and the lens chosen appropriately. The resulting magnification then would be 1:21.
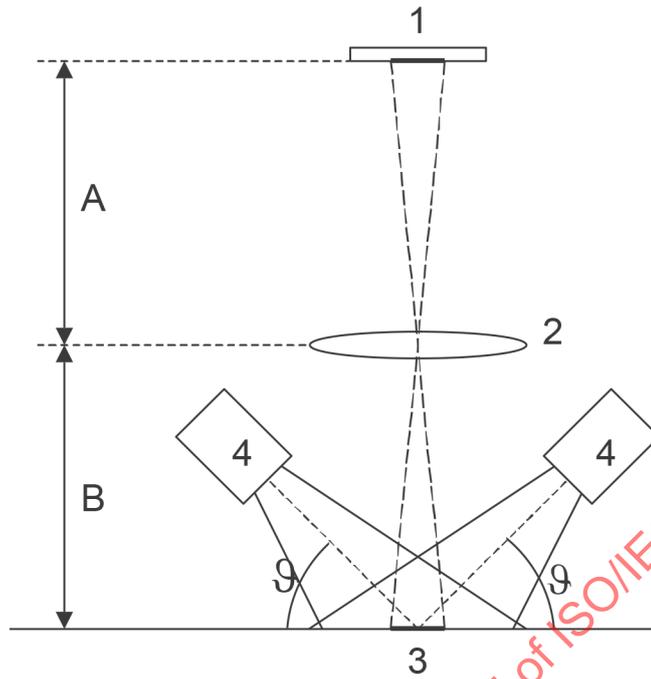
Key

1 light-sensing element
2 lens providing 1:1 magnification (measurement A = measurement B)
3 inspection area
4 light sources
ϑ angle of incidence of light relative to plane of symbol = 45°

Figure 1 — Reference optical arrangement — Side view
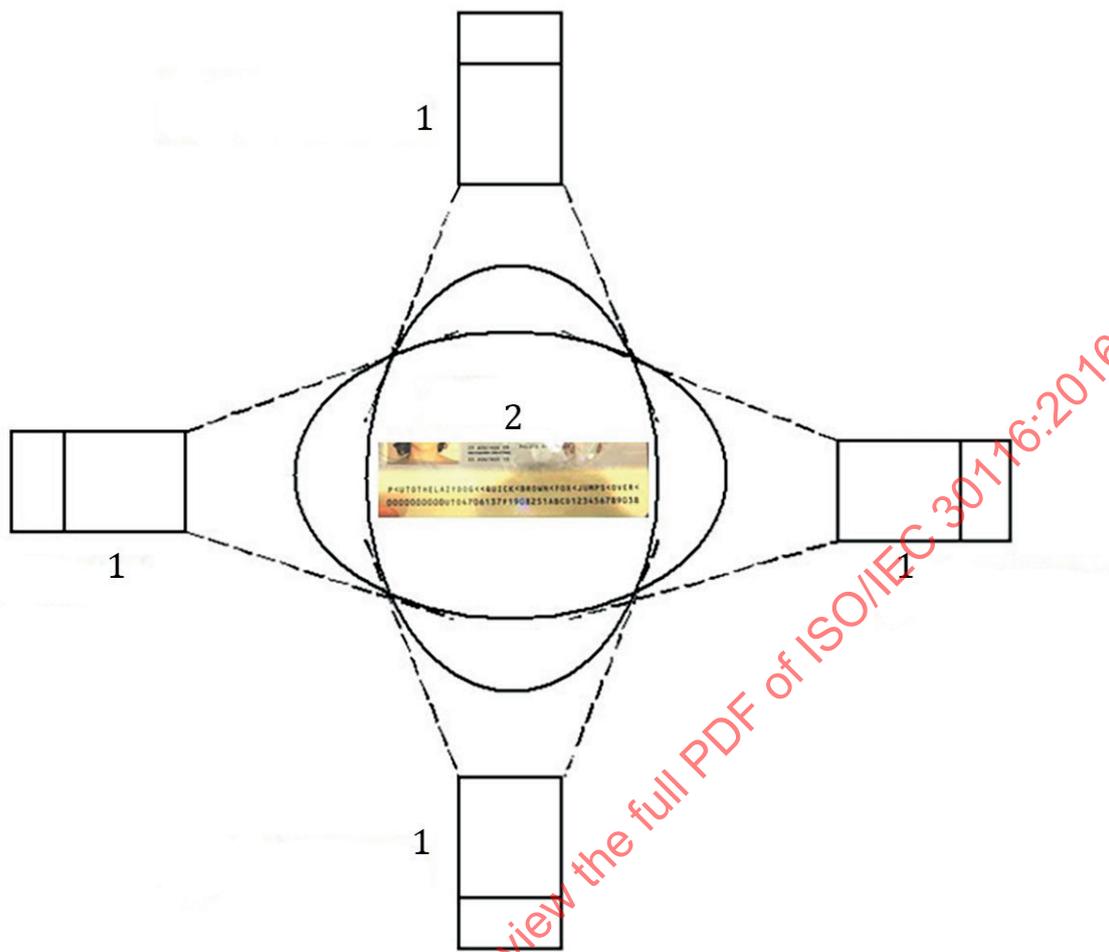
Key

1 light source
2 symbol

Figure 2 — Reference optical arrangement — Top view

MRZ small side

200

200

24

MRZ long side

200

200

125
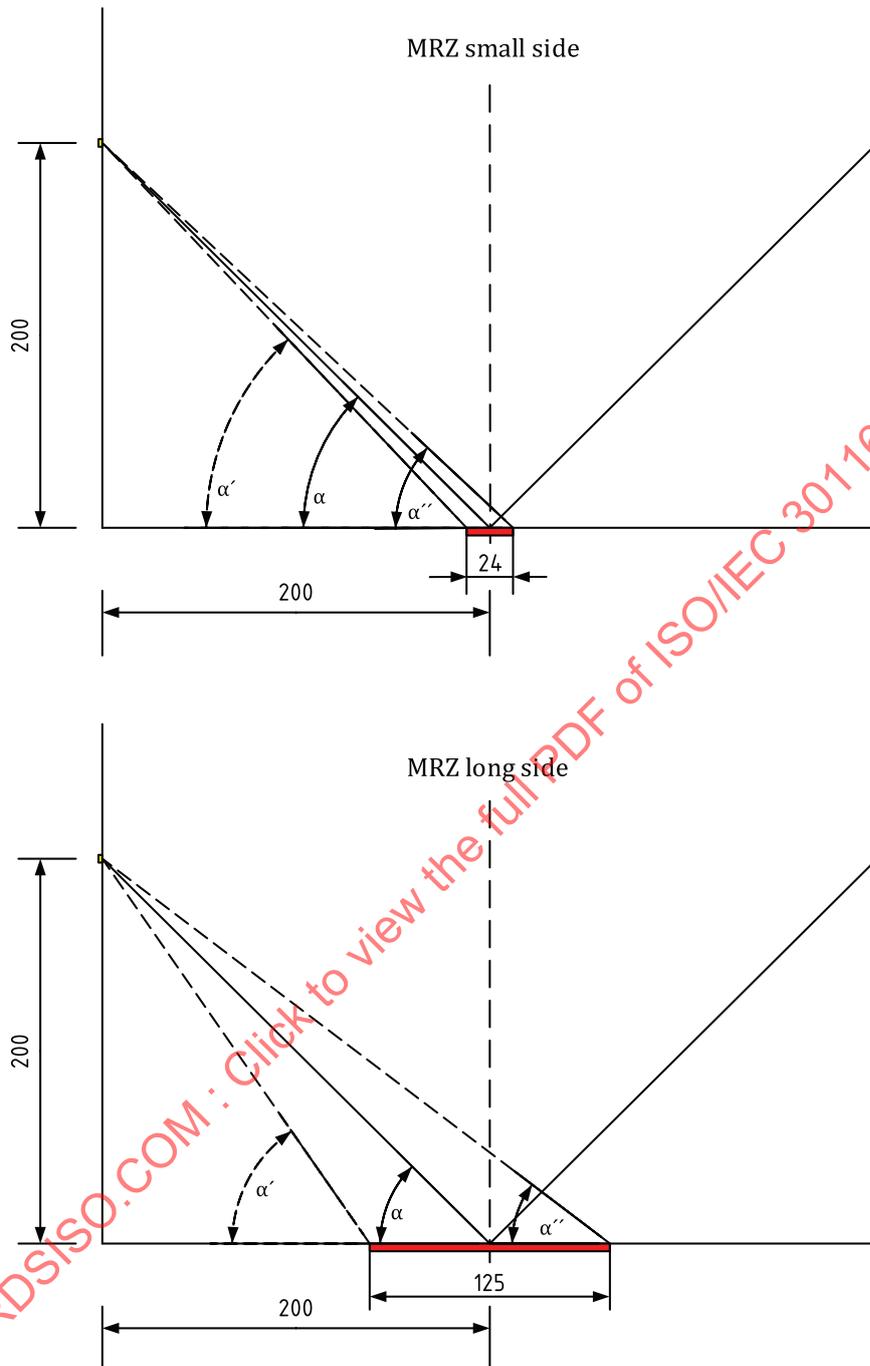
Figure 3 — Reference optical arrangement — Angles and tolerances

When setting up a reference optical arrangement, the following considerations shall be made. The symbol (e.g. the MRZ of an ID-3 MRTD) has a size of approximately 24 mm × 125 mm (marked as a bar in the bottom of Figure 3). For other document sizes (ID-1, ID-2), the same size of the object to be captured shall be used. All areas not covered by the travel document but visible to the camera shall be made of IR-absorbing material. The small rectangles at the left and right border of Figure 3 represent the illumination elements.

The nominal illumination angle shall be 45° as given in Figure 1. This angle is measured in the middle axis of the MRZ zone. An angle of 45° directly determines that the horizontal and vertical distance of the illumination from the centre of the symbol is identical. This distance should be 200 mm as depicted in Figure 3.

For the small side of the symbol (24 mm), the minimal and maximal illumination angles at the symbol borders are 43,3° and 46,8°, as shown in Table 1.

The difference between the nominal angle (in the centre) and the angles at the borders is much higher for the long side of the symbol; 37,3° and 55,5°.

Table 1 — Dark pixel portion for threshold of 4.5

Angle	Short side (24 mm)	Long side (125 mm)
α	45°	45°
α'	46,8°	55,5°
α''	43,3°	37,3°
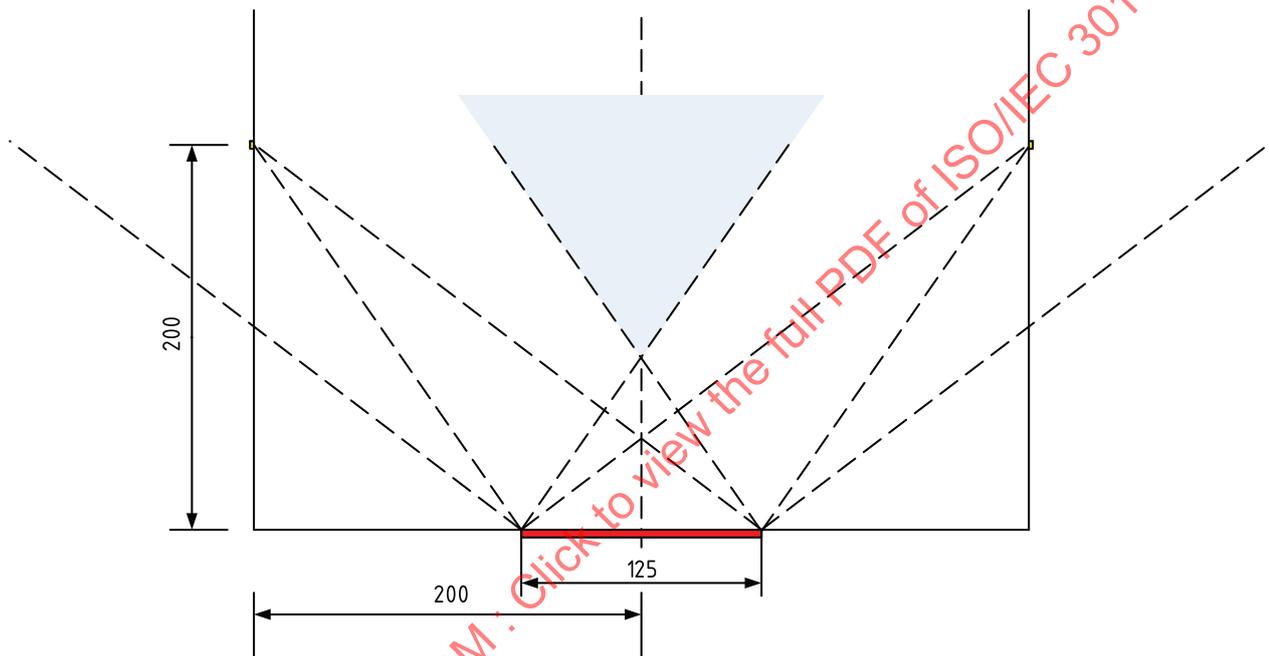
Figure 4 — Reference optical arrangement — Reflection considerations

Figure 4 shows the position where the direct reflection of the illumination at the symbol (i.e. caused by plain lamination) will not be visible to the camera. The distance between the camera and the symbol should be approximately 350 mm.

6.3.5   Inspection area

The inspection area within which all measurements shall be a rectangular area framing the complete symbol. The centre of the inspection area shall be as close as practicable to the centre of the field of view. For example, the MRZ in a passport shall be placed accordingly.

6.4   Basis of symbol grading

OCR symbol quality assessment shall be based on the measurement and grading of parameters of the reference grey-scale image, the binarized image derived from it and the application of the reference decode algorithm to these. Quality grading of these parameters shall be used to provide a relative measure of symbol quality under the measurement conditions used.

6.5   Capture the raw image

Centre the symbol in the field of view and align the average bottom edge of the characters with the sensor as precisely as possible, but always with less than +/−5° deviation.

Find and replace the brightest and darkest 0,005 % pixels in the overall image with the median of the 9 pixels consisting of itself and its 8 immediate neighbours.

Apply the aperture defined in 6.2.3 to the raw image to create a reference grey-scale image.

## 6.6   Image assessment parameters and grading

6.6.1   Determining the document horizontal axis

The application shall define the MRZ region in relation to the document reference edge.

6.6.2   Character best-fit algorithm

These steps should be followed in order to find the best-fit position of the character outline limit (SWT) gauges on a character image captured from a machine-readable character string in order to find the location of the characters.

Using the binarized image, determine four corner positions that bound the character image. From these points, establish four more points that are further away from the character by the nominal stroke width. These four points define the range over which the SWT gauges will be moved in order to find the best-fit position. An example is shown in Figure 5.
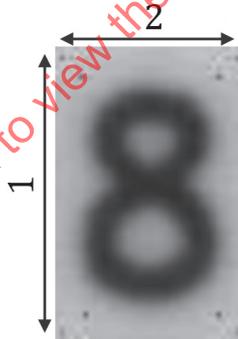
Key

1   vertical range
2   horizontal range

Figure 5 — Sample corner positions

Create the SWT for each defined character in Annex A by moving a circle of radius of the appropriate tolerance value around the centreline of the character and saving the outermost points (note that this is equivalent to finding the points perpendicular to the centre line at a distance equal to the radius of the circle). An example of this process is in Figure 6. Figure 7 illustrates the tolerances of the SWT boxes as derived from ISO 1831.
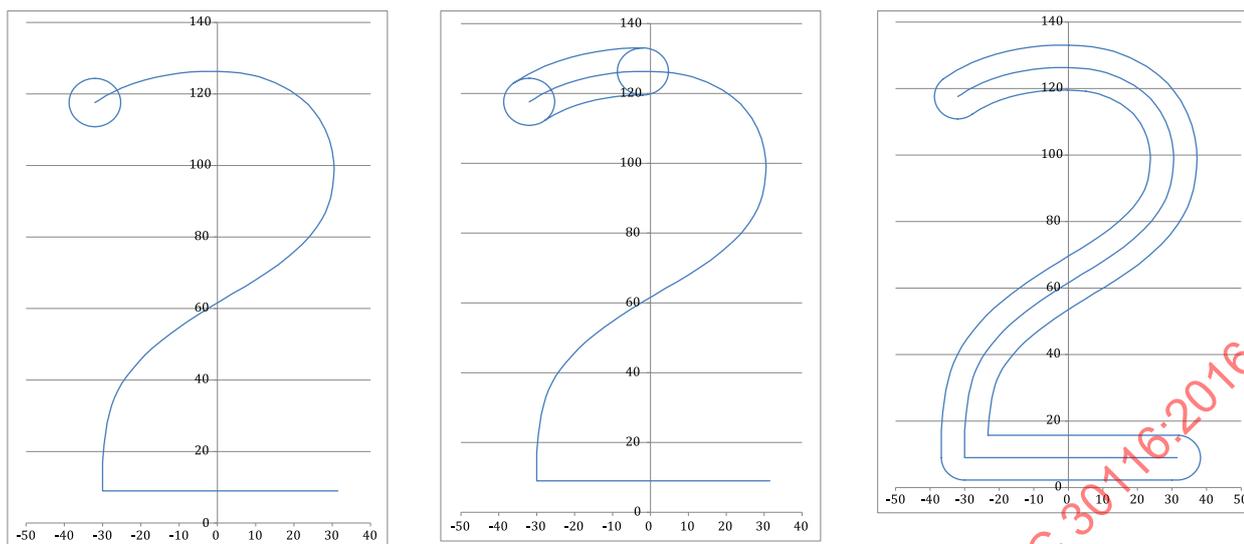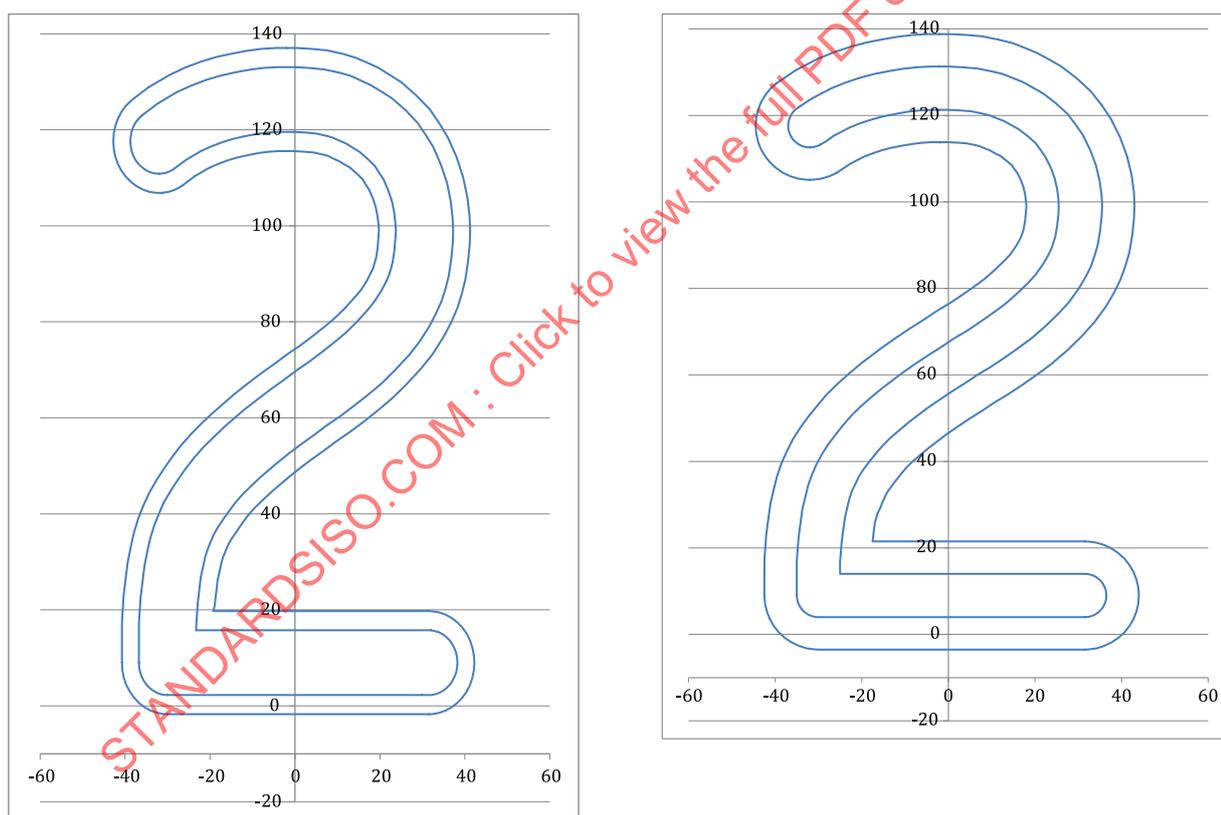
Figure 6 — SWT creation example

a) **X-tolerance. Radius 6,75 "sq" inside 10,75 "sq" outside**

b) **Y-tolerance. Radius 5 "sq" inside 12,5 "sq" outside**

NOTE 1   These are the tolerances from ISO 1831:1980, Table 2.

NOTE 2   "Sq" is the count of squares from the original drawings (see Annex A) where each square equals 1/50 mm.

Figure 7 — SWT tolerance gauges

Overlay the original captured image with the SWT Y-tolerance gauges such that the horizontal axis of the gauges is parallel with the document reference edge. Starting with the four extreme positions, move the SWT Y-tolerance gauges right and left and up and down relative to the document reference edge to each test position.

At each test position, sum up the reflectance values of each SWT Y-tolerance gauge resolution pixel within the region defined by the minimum gauge. The test position with the lowest sum is used to determine the position of the character. If there is more than one test position with the same lowest sum (e.g. the inside of the minimum gauge is all black), then for each equivalent test position, sum up the reflectance values of each gauge resolution pixel outside the maximum gauge. The equivalent test position with the highest sum is used to determine the position of the character. If there is more than one test position with the same highest sum, then compute the average of these positions and use it to determine the position of the character.

6.6.3 Position of a character

Using the test position determined in 6.6.2, the location of a character is the origin of the SWT, where the origin is defined as (0,0) for every character in Annex A.

The position of every character is determined and graded according to an application specific profile. The character with the lowest grade determines the position grade.

6.6.4 Character evaluation value (CEV) in the best-fit location

A pixel is outside or inside a border if more than 50 % of the pixel area is outside or inside the border, respectively.

For each tolerance template on every character, use the optimal position of the template placed over the binarized character in the image. The following lists the variables to be used to calculate the CEV grades:

a) CEV_X_Inside — number of white pixels inside the X-tolerance inner boundary;

b) CEV_X_Outside — number of black pixels outside the X-tolerance outer boundary;

c) CEV_Y_Inside — number of white pixels inside the Y-tolerance inner boundary;

d) CEV_Y_Outside — umber of black pixels outside the Y-tolerance outer boundary;

e) Y_Boundary_Area — total number of image pixels of any color inside the Y-tolerance outer boundary;

f) Y_Inside_Total — total number of image pixels of any color inside the Y-tolerance inner boundary;

g) Character_Region_Total — total number of image pixels in the rectangular area defined by the Y-tolerance outer template of the chosen character plus a one-stroke width boundary. The Character Region Total is computed as the product of the width of the Y-tolerance outer boundary plus two times the nominal stroke width rounded to the nearest number of pixels and the height of the Y-tolerance outer boundary plus the two times the nominal stroke width rounded to the nearest number of pixels.

From these measurements, compute the following graded parameters:

a) Character_Inside_Fit = CEV_Y_Inside / Y_Inside_Total

b) Character_Outside_Fit = CEV_Y_Outside / (Character_Region_Total − Y_Boundary_Area)

Grade the total results as follows.

a) Character_Inside_Fit > 10 % need attention

b) Character_Inside_Fit > 20 % not recommended

c) Character_Outside_Fit> 1 % need attention

d) Character_Outside_Fit > 2 % not recommended

The character with the lowest grade determines the character evaluation value (CEV) Grade of the entire MRZ.

NOTE   CEV_X_Inside and CEV_X_Outside are useful for process control.

See Annex C for the OCR reference decode algorithm. See Annex D for an example calculation of character evaluation value (CEV).

6.6.5   Background noise

Find the background noise, N.

Measure the maximum and minimum reflectance levels inside a rectangular area equal to the height and width of a character (1,4 mm × 2,4 mm) centred vertically between the two lines of text in the MRZ starting at the left end of the MRZ. Calculate N (noise) as the difference of the maximum reflectance minus the minimum reflectance all divided by the maximum reflectance within the box [(Rmax – Rmin) / Rmax] and save. Move the box a half character width and repeat. Continue to the end of the MRZ. Find the largest N.

It is recommended that the background non-uniformity is less than 15 %. Non-uniformity values between 15 % and 25 % need attention. It is not recommended that the non-uniformity value is above 25 %.

6.6.6   Contrast PCS of the characters

For all characters, determine Rmax by listing all the Rmax values from the background noise calculation. Rmax is equal to list value that is 80 % of the largest Rmax. To determine Rmin, centre an aperture of 0,2 mm on the best-fit centreline and move the aperture along the entire centreline in 20 micron steps. Form a list of all reflectance values. Rmin is equal to the list value that is 20 % of the smallest reflectance value. Contrast PCS for the character is (Rmax – Rmin) / Rmax. Perform the calculation on all characters. The character with the lowest PCS determines the Contrast PCS of the entire MRZ.

It is recommended that the PCS is greater than 0,6. PCS values between 0,5 and 0,6 need attention. It is not recommended that the PCS value is less than 0,5.

7   Reporting the grade

The grades are reported as follows.

For images at 890 nm:

a)   Character_Inside_Fit =

b)   Character_Outside_Fit =

c)   Character PCS =

d)   Position =

e)   Background Noise =

For images at 940 nm:

a)   Character_Inside_Fit =

b)   Character_Outside_Fit =

c)   Character PCS =

d)   Position =

e)   Background Noise =

The CEV Grade is the lowest of all the grades.

The CEV Grade =

Annex A
(normative)

OCR-B character centreline coordinates

The following coordinates were determined by inspection of high-resolution image scans of the original ISO 1073-2 OCR-B Size I centreline drawings of the ICAO 9303 subset currently in archival storage in the Stonybrook University Special Collections Library. For reference, the ICAO 9303 subset is as follows.

```
0123456789
ABCDEFGHI
JKLMNOPQR
STUVWXYZ<
```

The scale of the drawings is 50 squares per mm according to ISO 1073-2:1976, 3.6 which states that "the centreline height for the Type I character "8" = 2,40 mm". Going to the drawing, there are exactly 120 squares on the centreline of the character "8"; therefore, the scale is 50 squares per mm (120 / 2,4).

The units in the coordinates section are "number of squares", e.g. a value of (0,100) is the point 100 squares up from the origin on an original centreline drawing.

Format: The ordered pairs utilize a period (full stop) "." as a decimal mark and a comma "," to separate the horizontal and vertical coordinate values. Centreline coordinates begin with a semicolon (;) delimiter. Discontinuous lines are separated with another semicolon (;) delimiter. The end of the list is indicated by another semicolon (;) delimiter. Of note, the K and X centrelines do not touch.

```
Coordinates for Numeral "0"

;(0,6.5) (2,6.5) (5,6.6) (8,6.8) (11,7) (14,7.3) (16,7.7) (18,8.2) (20,9) (22,10)
(24,11.5) (25.3,13) (26.8,15) (28,17) (28.9,19) (29.7,21) (30.3,23) (30.9,25) (31.4,27)
(31.9,29) (32.3,31) (32.7,33) (33,35) (33.4,38) (33.8,41) (34.1,44) (34.3,47) (34.5,50)
(34.75,53) (34.9,56) (35,59) (35,71) (34.95,74) (34.8,77) (34.65,80) (34.4,83) (34.2,86)
(34,89) (33.7,92) (33.4,95) (33,98) (32.5,101) (32.1,103) (31.7,105) (31.2,107) (30.6,109)
(30,111) (29.3,113) (28.5,115) (27.4,117) (26.1,119) (24,121.3) (22,122.9) (20,123.9)
(18,124.6) (16,125.2) (13,125.8) (10,126.1) (7,126.3) (4,126.4) (2,126.5) (0,126.5)
(-2,126.5) (-4,126.4) (-7,126.3) (-10,126.1) (-13,125.8) (-16,125.2) (-18,124.6)
(-20,123.9) (-22,122.9) (-24,121.3) (-26.1,119) (-27.4,117) (-28.5,115) (-29.3,113)
(-30,111) (-30.6,109) (-31.2,107) (-31.7,105) (-32.1,103) (-32.5,101) (-33,98) (-33.4,95)
(-33.7,92) (-34,89) (-34.2,86) (-34.4,83) (-34.65,80) (-34.8,77) (-34.95,74) (-35,71)
(-35,59) (-34.9,56) (-34.75,53) (-34.5,50) (-34.3,47) (-34.1,44) (-33.8,41) (-33.4,38)
(-33,35) (-32.7,33) (-32.3,31) (-31.9,29) (-31.4,27) (-30.9,25) (-30.3,23) (-29.7,21)
(-28.9,19) (-28,17) (-26.8,15) (-25.3,13) (-24,11.5) (-22,10) (-20,9) (-18,8.2) (-16,7.7)
(-14,7.3) (-11,7) (-8,6.8) (-5,6.6) (-2,6.5) (0,6.5);


Coordinates for the "1"

;(-29.5,98.8) (2,126) (7.5,126) (5.5,7);


Coordinates for the "2"

;(-32,117.6) (-31,118.2) (-29,119.6) (-25,121.7) (-22,122.9) (-19,123.9) (-16,124.7)
(-13,125.3) (-10,125.8) (-7,126.15) (-4,126.3) (-2,126.3) (0,126.3) (3,126.15) (6,125.9)
(9,125.3) (11,124.8) (13,124) (15,123.2) (17,122.1) (19,121) (21.6,119) (23.8,117)
(25.3,115) (26.7,113) (28.2,110) (29.3,107) (30,104) (30.4,101) (30.5,99) (30.4,97)
(30.1,94) (29.6,91) (29,89) (28.3,87) (27.3,85) (26,82.8) (24,80) (22,77.8) (19,74.9)
(16,72.3) (13,70.1) (10,68) (7,66) (4,64.2) (1,62.2) (-2,60.3) (-5,58.3) (-8,56.2)
```

(-12.2,53) (-14.6,51) (-16.9,49) (-18.9,47) (-20.6,45) (-22.2,43) (-23.7,41) (-25,39)
(-26,37) (-26.9,35) (-27.6,33) (-28.1,31) (-28.8,28) (-29.2,25) (-29.6,22) (-30,17)
(-30,9) (31.5,9);

Coordinates for the "3"

;(-34.5,124) (29,124) (29,118) (-11,76) (-8,76) (-5,75.8) (-2,75.4) (1,75) (4,74.3)
(6,73.9) (8,73.2) (10,72.6) (12,71.8) (14,70.9) (16,69.9) (18,68.8) (20,67.4) (23.1,65)
(25.2,63) (27,61) (28.4,59) (29.7,57) (30.7,55) (31.5,53) (32.4,50) (33,47) (33.4,44)
(33.5,41) (33.2,38) (32.9,35) (32.3,32) (31.7,30) (31,28) (30.1,26) (29,24) (27.6,22)
(26.2,20) (24,17.8) (22,15.9) (20,14.4) (18,13.1) (16,12) (14,10.9) (12,10.1) (9,9)
(6,8.2) (3,7.5) (0,7) (-3,6.7) (-6,6.5) (-9,6.5) (-13,6.8) (-16,7) (-19,7.3) (-21,7.7)
(-23,8) (-25,8.5) (-27,9) (-29,9.7) (-32,10.8) (-35,12);

Coordinates for the "4"

;(3,126) (-35,45) (-35,37.5) (35,37.5); (17,66.5) (17,7);

Coordinates for the "5"

;(27,124) (-24.4,124) (-27,80.2) (-24,80.6) (-21,80.9) (-18,81) (-14,81) (-11,80.9)
(-9,80.8) (-6,80.5) (-3,80) (0,79.6) (3,79) (6,78.1) (8,77.4) (10,76.6) (12,75.5)
(14,74.4) (16,73) (18.5,71) (20.4,69) (22,67) (23.4,65) (24.6,63) (25.5,61) (26.6,58)
(27.4,55) (27.9,52) (28,49) (28,46) (27.9,43) (27.5,40) (26.9,37) (26,34) (25.1,32)
(24.2,30) (23,28) (21.7,26) (20,24) (18.2,22) (16,20) (14,18.3) (12,16.9) (10,15.7)
(8,14.5) (6,13.4) (4,12.5) (2,11.8) (0,11) (-2,10.2) (-4,9.7) (-7,8.9) (-10,8.2) (-13,7.8)
(-16,7.4) (-19,7.1) (-22,6.9) (-25,6.8) (-28,6.7) (-30.6,6.7);

Coordinates for the "6"

(13,126) (10.2,123) (7.3,120) (4.6,117) (1.8,114) (0,112) (-3.5,108) (-6,105) (-8.6,102)
(-10.9,99) (-13.1,96) (-15.3,93) (-17.5,90) (-19.5,87) (-21.5,84) (-23.4,81) (-25,78)
(-26.7,75) (-27.7,73) (-28.6,71) (-29.5,69) (-30.4,67) (-31.1,65) (-31.8,63) (-32.5,61)
(-33,59) (-33.6,57) (-34,55) (-34.3,53) (-34.6,51) (-34.9,49) (-35,47) (-35,45) (-35,39)
(-34.8,36) (-34.2,33) (-33.8,31) (-33.2,29) (-32.6,27) (-31.7,25) (-30.8,23) (-29.5,21)
(-28,19) (-26,17) (-24,14.9) (-22,13.1) (-20,11.8) (-18,10.6) (-16,9.6) (-14,8.9)
(-12,8.1) (-10,7.6) (-8,7.1) (-6,6.9) (-4,6.7) (-2,6.55) (0,6.5) (2,6.55) (4,6.8) (6,7)
(8,7.2) (10,7.7) (12,8.2) (14,9) (16,9.7) (18,10.6) (20,11.8) (22,13.1) (24,14.8)
(26,16.8) (28,19) (29.4,21) (30.6,23) (31.6,25) (32.4,27) (33,29) (33.6,31) (34.1,33)
(34.6,36) (34.9,39) (35,42) (34.9,45) (34.5,48) (34,51) (33.5,53) (33,55) (32.2,57)
(31.3,59) (30.2,61) (29,63) (27.4,65) (26,66.7) (24,68.6) (22,70.2) (20,71.7) (18,72.8)
(16,73.7) (14,74.5) (12,75.1) (9,75.9) (6,76.2) (3,76.4) (0,76.5) (-3,76.4) (-6,76.2)
(-9,75.8) (-12,75.1) (-14,74.5) (-16,73.7) (-18,72.8) (-20,71.6) (-22,70.2) (-24,68.6)
(-25.6,67) (-27.5,65) (-29,63) (-30.2,61) (-31.4,59) (-32.2,57) (-32.9,55) (-33.5,53)
(-34,51) (-34.2,50) (-34.6,48) (-34.9,46) (-35,41);

Coordinates for the "7"

;(-35,124) (35,124) (35,122) (34.9,120) (34.7,118) (34.4,116) (34.1,114) (33.5,112)
(32.8,110) (31.8,108) (30.5,106) (29,103.9) (27,101.2) (24,97.8) (21,94.3) (18,91)
(15,87.4) (12,83.8) (9,79.9) (6.9,77) (4.8,74) (2.8,71) (0.8,68) (-1,65) (-2.7,62)
(-4.2,59) (-5.6,56) (-6.9,53) (-8,50) (-8.9,47) (-9.7,44) (-10.5,41) (-11.1,38) (-11.7,35)
(-12.1,32) (-12.4,29) (-12.8,26) (-12.9,23) (-13,20) (-13,7);

Coordinates for the "8"

;(0,126.5) (2,126.45) (5,126.3) (8,125.8) (11,125.1) (14,124.1) (16,123.3) (18,122.2)
(20,121) (22,119.4) (23.5,118) (25.1,116) (26.3,114) (27.3,112) (28.1,110) (28.7,108)
(28.9,106) (29,104) (28.9,102) (28.6,100) (28.1,98) (27.5,96) (26.5,94) (25.3,92) (24,90)
(22.2,88) (20,86) (17,83.5) (14,81.3) (11,79.5) (8,77.8) (5,76.2) (0,73.7) (5,71.1)
(8,69.5) (11,67.8) (14,66.1) (17,64.2) (20,62.2) (22,60.7) (24,59) (26.2,57) (28,55)
(29.6,53) (30.9,51) (32,49) (32.9,47) (33.6,45) (34.2,43) (34.6,41) (34.9,39) (35,37)
(35,35) (34.9,33) (34.6,31) (34.2,29) (33.8,27) (33.1,25) (32.3,23) (31.3,21) (30,19)
(29,17.5) (27,15.3) (25,13.6) (23,12.1) (21,10.9) (19,10) (17,9.1) (14,8.2) (11,7.5) (8,7)
(5,6.7) (2,6.55) (0,6.5) (-2,6.55) (-5,6.7) (-8,7) (-11,7.5) (-14,8.2) (-17,9.1) (-19,10)

(-21,10.9) (-23,12.1) (-25,13.6) (-27,15.3) (-29,17.5) (-30,19) (-31.3,21) (-32.3,23)
(-33.1,25) (-33.8,27) (-34.2,29) (-34.6,31) (-34.9,33) (-35,35) (-35,37) (-34.9,39)
(-34.6,41) (-34.2,43) (-33.6,45) (-32.9,47) (-32,49) (-30.9,51) (-29.6,53) (-28,55)
(-26.2,57) (-24,59) (-22,60.7) (-20,62.2) (-17,64.2) (-14,66.1) (-11,67.8) (-8,69.5)
(-5,71.1) (0,73.7) (-5,76.2) (-8,77.8) (-11,79.5) (-14,81.3) (-17,83.5) (-20,86)
(-22.2,88) (-24,90) (-25.3,92) (-26.5,94) (-27.5,96) (-28.1,98) (-28.6,100) (-28.9,102)
(-29,104) (-28.9,106) (-28.7,108) (-28.1,110) (-27.3,112) (-26.3,114) (-25.1,116)
(-23.5,118) (-22,119.4) (-20,121) (-18,122.2) (-16,123.3) (-14,124.1) (-11,125.1)
(-8,125.8) (-5,126.3) (-2,126.45) (0,126.5);

Coordinates for the "9"

;(-13,7) (-10,10.1) (-7,13.2) (-4,16.4) (-1.6,19) (1,22) (3.6,25) (6.2,28) (8.6,31)
(10.9,34) (13.2,37) (15.3,40) (17.5,43) (19.6,46) (21.5,49) (23.2,52) (24.4,54) (26.1,57)
(27.6,60) (29.1,63) (30.3,66) (31.5,69) (32.5,72) (33.3,75) (34,78) (34.5,81) (34.8,84)
(35,87) (35,93) (34.8,96) (34.3,99) (33.7,102) (32.8,105) (31.6,108) (31.1,109) (30,111)
(28.7,113) (27.1,115) (25,117.2) (23,119) (20,121.2) (17,122.8) (14,124.1) (11,125.1)
(8,125.8) (5,126.2) (3,126.4) (1,126.5) (-1,126.4) (-4,126.2) (-7,125.9) (-10,125.2)
(-13,124.4) (-16,123.3) (-19,121.8) (-22,119.8) (-24,118.3) (-26,116.4) (-28,114)
(-29.5,112) (-30.6,110) (-31.7,108) (-32.5,106) (-33.2,104) (-34,101) (-34.5,98)
(-34.9,95) (-35,92) (-35,89) (-34.7,86) (-34.2,83) (-33.5,80) (-33,78) (-32.2,76)
(-31.4,74) (-30.3,72) (-29,70) (-27.5,68) (-26,66.2) (-24,64.3) (-22,62.7) (-19,60.8)
(-16,59.3) (-13,58.2) (-10,57.4) (-7,56.8) (-4,56.4) (-2,56.3) (2,56.3) (5,56.7) (8,57)
(11,57.7) (14,58.7) (17,59.9) (20,61.4) (23,63.5) (25,65.2) (27,67.3) (29.1,70) (30.3,72)
(31.4,74) (32.2,76) (33,78) (33.6,80) (34,82) (34.4,84) (34.8,86) (34.9,88) (35,90);

Coordinates for the "A"

;(-34,7) (-6,116) (6,116) (34,7); (24.5,43.5) (-24.5,43.5);

Coordinates for the "B"

;(-35,114) (-3,114) (0,113.9) (3,113.8) (6,113.6) (9,113.2) (12,112.8) (15,112) (17,111.3)
(19,110.4) (21,109.4) (23,108) (25,106.5) (26.4,105) (28.1,103) (29.4,101) (30.4,99)
(31.2,97) (31.8,95) (32.1,93) (32.3,91) (32.5,89) (32.4,87) (32.2,85) (31.9,83) (31.3,81)
(30.7,79) (29.8,77) (28.5,75) (27,73) (25,70.8) (23,69.3) (21,68) (19,66.9) (17,66)
(15,65.4) (13,64.8) (11,64.4) (9,64.1) (7,64.05) (3,64) (-35,64) (3,64) (5,63.9) (7,63.8)
(9,63.6) (11,63.35) (13,63) (15,62.5) (17,61.9) (19,61.1) (21,60.2) (23,59) (25,57.6)
(27,55.8) (28.8,54) (30.2,52) (31.6,50) (32.6,48) (33.4,46) (34,44) (34.6,42) (34.9,40)
(35,38) (35,36) (34.9,34) (34.6,32) (34.2,30) (33.6,28) (32.8,26) (31.9,24) (30.9,22)
(29.3,20) (28,18.5) (26,16.8) (24,15.1) (22,13.9) (20,12.8) (18,12) (16,11.3) (13,10.4)
(10,9.8) (7,9.4) (4,9.1) (0,9) (-35,9) (-35,114);

Coordinates for the "C"

;(27,101) (26.5,103) (25.8,105) (25,106.5) (24,108) (22.3,110) (20,112) (17,113.9)
(14,115.1) (10,116) (5.5,116.5) (0,116) (-3.5,115) (-6.3,114) (-9.6,112) (-12,110)
(-14.9,107) (-17,104) (-19.5,100) (-21.6,95) (-23.8,88) (-25.4,80) (-26,73) (-26.5,66)
(-26.5,60) (-26,51) (-25,42) (-23.2,33) (-21.3,27) (-19,22) (-16,17) (-12.4,13) (-8.5,10)
(-5,8.3) (-1,7.1) (2,6.7) (5.5,6.5) (9,6.7) (12,7.1) (16,8.5) (19,10) (21.5,12) (23.4,14)
(25,16.2) (26,18) (26.6,20) (27,22);

Coordinates for the "D"

;(-26,114) (-20,114) (-13,113.1) (-7.7,112) (-4,110.8) (-0.5,109) (3,107) (7.4,104)
(11,101) (14,98) (17.5,94) (20.6,90) (23.2,86) (26.1,80) (27.7,76) (29.2,70) (30,64)
(30.5,58) (30,52) (29,46) (27.8,41) (26,37) (23.3,32) (20.8,28) (17.4,24) (13.3,20)
(10,17.4) (6,14.8) (1,12.5) (-3.2,11) (-7.5,10) (-13,9.3) (-20,9) (-26,9) (-26,114);

Coordinates for the "E"

;(-26.5,114) (-26.5,9); (-26.5,114) (31,114); (-26.5,64) (24.4,64); (-26.5,9) (33,9);

Coordinates for the "F"

;(30,114) (-18,114) (-18,7); (-18,64) (22,64);

Coordinates for the "G"

;(30.5,104.5) (29,106.8) (27,109) (25,110.7) (23,112) (20,113.6) (17,114.9) (14,115.6) (11,116) (8,116.4) (5,116.5) (3,116.4) (0,116) (-3,115.6) (-6,114.9) (-9,113.8) (-11,113) (-13,111.9) (-15,110.6) (-17,109) (-19,107.3) (-21,105.2) (-23,102.6) (-24.8,100) (-26.5,97) (-27.9,94) (-29,91) (-30.2,87) (-31.2,83) (-31.9,79) (-32.4,75) (-32.8,71) (-33,65) (-32.9,58) (-32.7,53) (-32.4,49) (-32,44.6) (-31.1,40) (-30.2,36) (-29,32) (-27.9,29) (-26.5,26) (-25,23) (-23.2,20) (-21.8,18) (-20,16) (-18,14) (-15.5,12) (-12.2,10) (-9,8.6) (-6,7.7) (-3,7) (0,6.6) (3,6.5) (7,6.5) (7,6.6) (12,6.9) (16,7.3) (19,8) (22,8.8) (25,9.8) (28,11) (32,13) (32,57.5) (3.5,57.5);

Coordinates for the "H"

;(-30,116) (-30,7); (-30,63) (30,63); (30,116) (30,7);

Coordinates for the "I"

;(-21.5,114) (21.5,114); (0,114) (0,9); (-25,9) (25,9);

Coordinates for the "J"

;(13.5,116) (13.5,36) (13.45,33) (13.3,30) (13,26) (12.6,23) (12,20.7) (11,18) (9.4,15) (6.9,12) (5,10.5) (2,8.6) (-2,7.2) (-6,6.5) (-9,6.4) (-12,6.6) (-16,7.2) (-20,8.8) (-23,10.6) (-25,12.3) (-27.4,15) (-29.1,18) (-30,20.4) (-30.7,22) (-31.1,26) (-31.4,30) (-31.5,33.5);

Coordinates for the "K"

;(-32.5,116) (-32.5,7); (31,116) (-20,64) (35,7);

Coordinates for the "L"

;(-30,116) (-30,9) (35,9);

Coordinates for the "M"

;(-35,116) (-35,7) (-35,116) (-21.5,116) (0,45) (21.5,116) (35,116) (35,7);

Coordinates for the "N"

;(-32.5,7) (-32.5,116) (-26,116) (27,7) (32.5,7) (32.5,116);

Coordinates for Letter "O"

;(0,6.5) (2,6.6) (4,6.8) (6,7.1) (8,7.6) (10,8.2) (12,9.2) (14,10.5) (16,12) (18,13.8) (20.1,16) (21.8,18) (23.05,20) (24.3,22) (25.5,24) (26.6,26) (27.6,28) (28.5,30) (29.2,32) (30,34) (30.7,36) (31.2,38) (31.8,40) (32.2,42) (32.7,44) (33.3,47) (33.7,50) (34.1,54) (34.35,57) (34.47,60) (34.5,62) (34.4,65) (34.25,68) (33.85,72) (33.5,75) (33,78) (32.3,81) (31.6,84) (31.1,86) (30.5,88) (29.5,91) (28.7,93) (27.9,95) (26.9,97) (26,99) (24.9,101) (23.7,103) (22.3,105) (21,106.8) (19,109.1) (17,111) (15,112.6) (13,114) (11,115.1) (9,115.9) (7,116.6) (4,117.2) (2,117.4) (0,117.5) (-2,117.4) (-4,117.2) (-7,116.6) (-9,115.9) (-11,115.1) (-13,114) (-15,112.6) (-17,111) (-19,109.1) (-21,106.8) (-22.3,105) (-23.7,103) (-24.9,101) (-26,99) (-26.9,97) (-27.9,95) (-28.7,93) (-29.5,91) (-30.5,88) (-31.1,86) (-31.6,84) (-32.3,81) (-33,78) (-33.5,75) (-33.85,72) (-34.25,68) (-34.4,65) (-34.5,62) (-34.47,60) (-34.35,57) (-34.1,54) (-33.7,50) (-33.3,47) (-32.7,44) (-32.2,42) (-31.8,40) (-31.2,38) (-30.7,36) (-30,34) (-29.2,32) (-28.5,30) (-27.6,28) (-26.6,26) (-25.5,24) (-24.3,22) (-23.05,20) (-21.8,18) (-20.1,16) (-18,13.8) (-16,12) (-14,10.5) (-12,9.2) (-10,8.2) (-8,7.6) (-6,7.1) (-4,6.8) (-2,6.6) (0,6.5);

Coordinates for the "P"

;(-30,114) (4,114) (7,113.9) (11,113.4) (14,112.9) (17,112) (20,110.9) (22,110) (24,108.8)
(26,107) (28,105.1) (30,102.7) (31.8,100) (33,97) (34,94) (34.6,91) (35,88) (35,85)
(34.6,82) (34,78.8) (33.2,76) (32,73.5) (30,70) (28,67.6) (26,65.7) (24,64) (22,62.9)
(20,62) (17,60.8) (14,60) (11,59.5) (7,59.1) (4,59) (-30,59); (-30,114) (-30,7);

Coordinates for the "Q"

;(-2.5,116.5) (1,116.2) (5,115.5) (9,114) (13,111.5) (17,108) (20.3,104) (24,98) (26.4,92)
(28.2,85) (29.3,78) (30,70) (30,60) (29.3,52) (28,45) (26,38) (23.2,32) (21,28) (18,24)
(14,20.2) (11,18.1) (7,16.1) (2.8,15) (-2.5,14.5) (-7.6,15) (-12,16.2) (-15.7,18)
(-19,20.2) (-23,24) (-26,28) (-28.5,32) (-31,38) (-33,45) (-34,50) (-35,60) (-35,70)
(-34.4,78) (-33.3,85) (-31.5,92) (-29,98) (-25.5,104) (-22.1,108) (-18,111.5) (-14,113.9)
(-10,115.5) (-6,116.2) (-2.5,116.5); (-1.5,54) (35,7);

Coordinates for the "R"

;(-28,114) (-4,114) (0,113.9) (3,113.8) (6,113.5) (9,113) (12,112.3) (14,111.7) (16,110.7)
(18,109.6) (20,108.3) (22,106.7) (23.6,105) (25.2,103) (26.5,101) (27.5,99) (28.2,97)
(29.2,94) (29.8,91) (30,89) (30,85) (29.9,83) (29.3,80) (28.5,77) (27.7,75) (26.8,73)
(25.6,71) (24,69) (22,66.8) (20,65.2) (18,63.8) (16,62.7) (14,61.8) (11,60.7) (9,60.1)
(6,59.5) (3,59.1) (0,59) (-4,59) (-28,59); (-28,114) (-28,7); (-28,59); (1,59) (31,7);

Coordinates for the "S"

;(27.4,99) (26.8,101) (25.4,104) (23.4,107) (20.6,110) (18,111.9) (15,113.6) (12,114.8)
(9,115.6) (6,116.1) (3,116.4) (0,116.5) (-3,116.3) (-6,116) (-9,115.3) (-12,114.3)
(-15,113) (-18,111.1) (-21,108.8) (-23.7,106) (-25.6,103) (-26.9,100) (-27.7,97) (-28,94)
(-27.9,90) (-27.3,87) (-26.3,84) (-24.8,81) (-22.7,78) (-20,75.2) (-17,73) (-14,71)
(-10,68.8) (-6,66.9) (-1,64.6) (4,62.1) (9,59.7) (13,57.2) (17,54.5) (20,52) (23,49)
(25.2,46) (26.9,43) (28,40) (28.9,36) (29,33) (28.9,30) (28.5,27) (27.6,24) (26.4,21)
(24.6,18) (22,15) (18.3,11.8) (16,10.5) (13,9.1) (10,8.05) (7,7.4) (4,6.9) (1,6.6)
(-2,6.5) (-5,6.6) (-8,7) (-11,7.6) (-14,8.5) (-17,9.8) (-20.7,12) (-24,15) (-26,18)
(-27.5,21) (-28.4,24) (-28.8,26) (-29,28);

Coordinates for the "T"

;(-35,114) (35,114) (0,114) (0,7);

Coordinates for the "U"

;(32.5,116) (32.5,40) (32.4,37) (32.2,34) (31.9,31) (31.4,28) (30.5,25) (29.4,22)
(27.9,19) (25.5,16) (23,13.6) (20,11.6) (17,10) (14,8.6) (11,7.8) (8,7.1) (5,6.8) (2,6.6)
(0,6.5) (-2,6.6) (-5,6.8) (-8,7.1) (-11,7.8) (-14,8.6) (-17,10) (-20,11.6) (-23,13.6)
(-25.5,16) (-27.9,19) (-29.4,22) (-30.5,25) (-31.4,28) (-31.9,31) (-32.2,34) (-32.4,37)
(-32.5,40) (-32.5,116);

Coordinates for the "V"

;(-35,116) (-6,7) (6,7) (35,116);

Coordinates for the "W"

;(-35,116) (-34.5,102) (-33.5,83) (-32.5,68) (-31.5,57) (-29.9,41) (-28.8,33) (-27.5,25)
(-26.4,19) (-25.5,14) (-24.6,10) (-24,7) (-19,7) (-1.5,67.5) (1.5,67.5) (19,7) (24,7)
(24.6,10) (25.5,14) (26.4,19) (27.5,25) (28.8,33) (29.9,41) (31.5,57) (32.5,68) (33.5,83)
(34.5,102) (35,116);

Coordinates for the "X"

;(-30.5,116) (-1,63) (-31.5,7); (30.5,116) (1,63) (31.5,7);

```
Coordinates for the "Y"
;(-31,116) (0,57.5) (0,7); (0,57.5) (31,116);

Coordinates for the "Z"
;(-29.5,114) (24,114) (-30,9) (30,9);

Coordinates for the "<"
;(35,113) (-35,66.5) (35,20);
```

19

Annex B
(normative)

Threshold determination method

B.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 minVariance to a very large number and initialize Tmin and Tmax to zero.

b) For every grey-scale value, "t", 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 t and call it MeanDark and VarianceDark

2) compute the mean and variance of pixels above or equal to t and call it MeanLight and VarianceLight

3) compute Variance = VarianceLight + VarianceDark.

4) if Variance < minVariance, save Variance in minVariance and save t in Tmin, and

5) if Variance = minVariance save t in Tmax.

NOTE   Step 5 is used to break ties. Tmin is the smallest grey-level where the variance is the minimum and Tmax is the largest grey-level where the variance is the same minimum.

c) Optimal threshold, T = (Tmin + Tmax) / 2.

B.2 Example

For simplicity, an image with only 100 pixels (a 10 × 10 image) will be 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 B.1, where each pixel is magnified so that individual pixels can be discerned.
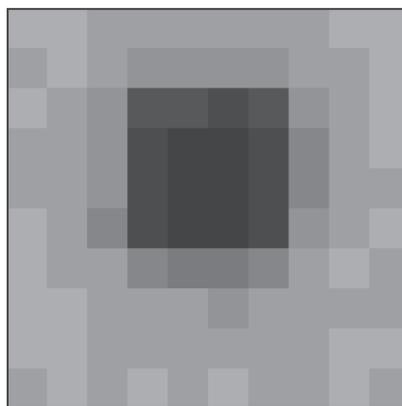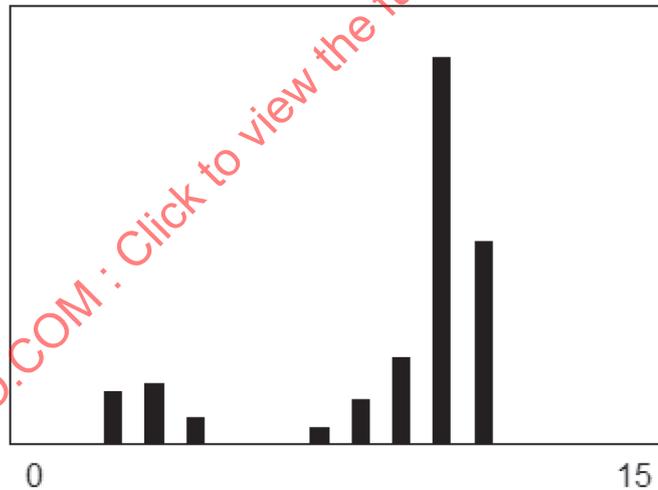

Figure B.1 — Image used in this example

We 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 B.1 and is plotted as a histogram in Figure B.2.

Table B.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 B.2 — Histogram of the data from Table B.1

For each possible threshold, we separate the histogram 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 B.2.

Table B.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 B.2.

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

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

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

In likewise fashion, the variances of the dark and light portions of the histogram for each threshold can be computed. The results are shown in Table B.3.

Table B.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 B.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 gives 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