



Information technology — Automatic identification and data capture techniques — Data Matrix bar code symbology specification

TECHNICAL CORRIGENDUM 2

*Technologies de l'information — Techniques automatiques d'identification et de capture des données —
Spécification de symbologie de code à barres Data Matrix*

RECTIFICATIF TECHNIQUE 2

Technical Corrigendum 2 to ISO/IEC 16022:2006 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

Page 28

Replace Clause 9 with the following:

9 Reference decode algorithm for Data Matrix

This reference decode algorithm finds a Data Matrix symbol in an image and decodes it.

- a) Define measurement parameters and form a digitised image:
 - 1) Define a distance d_{min} which is 7,5 times the aperture diameter defined by the application. This will be the minimum length of the "L" pattern's side.

- 2) Define a distance g_{max} which is 7,5 times the aperture diameter. This is the largest gap in the "L" finder that will be tolerated by the finder algorithm in step b).
 - 3) Define a distance m_{min} which is 1,25 times the aperture diameter. This would be the nominal minimum module size when the aperture size is 80% of the symbol's X dimension.
 - 4) Form a black/white image using a threshold determined according to the method defined in ISO/IEC 15415.
- b) Search horizontal and vertical scan lines for the two outside edges of the Data Matrix "L":
- 1) Extend a scan line horizontally in both directions from the centre point of the image. Sample along the scan line. For each white/black or black/white transition found along the scan line resolved to the pixel boundary:
 - i) Follow the edge upward sampling pixel by pixel until either it reaches a point $3,5m_{min}$ distant from the intersection of the scan line and the edge starting point, or the edge turns back toward the intersection of the scan line and the edge - the starting point.
 - ii) Follow the edge downward pixel by pixel until either it reaches a point $3,5m_{min}$ distant from the intersection of the scan line and the edge starting point, or the edge turns back toward the intersection of the scan line and the edge - the starting point.
 - iii) If the upward edge reaches a point $3,5m_{min}$ from the starting point:
 - I) Plot a line A connecting the end points of the upward edge.
 - II) Test whether the intermediate edge points lie within $0,5m_{min}$ from line A. If so, continue to step III. Otherwise proceed to step 1)iv) to follow the edge in the opposite direction.
 - III) Continue following the edge upward until the edge departs $0,5m_{min}$ from line A. Back up to the closest edge point greater than or equal to m_{min} from the last edge point along the edge before the departing point and save this as the edge end point. This edge point should be along the "L" candidate outside edge.
 - IV) Continue following the edge downward until the edge departs $0,5m_{min}$ from line A. Back up to the closest edge point greater than or equal to m_{min} from the last edge point along the edge before the departing point and save this as the edge end point. This edge point should be along the "L" candidate outside edge.
 - V) Calculate a new adjusted line A1 that is a "best fit" line to the edge in the two previous steps. The "best fit" line uses the linear regression algorithm (using the end points to select the proper dependent axis, i.e. if closer to horizontal, the dependent axis is x) applied to each point. The "best fit" line terminates lines at points p1 and p2 that are the points on the "best fit" line closest to the endpoints of the edge.
 - VI) Save the line A1 segment two end points, p1 and p2. Also save the colour of the left side of the edge viewed from p1 to p2.
 - iv) If step iii) failed or did not extend upward by $3,5m_{min}$ in step iii)IV), test if the downward edge reaches a point $3,5m_{min}$ from the starting point. If so, repeat the steps in iii) but with the downward edge.
 - v) If neither steps iii) or iv) were successful, test if both the upward and downward edges terminated at least $2m_{min}$ from the starting point. If so, form an edge comprised of the appended $2m_{min}$ length upward and downward edge segments and repeat the steps in iii) but with the appended edge.
 - vi) Proceed to and process the next transitions on the scan line, repeating from step i), until the boundary of the image is reached.

- 2) Extend a scan line vertically in both directions from the centre point of the image. Look for line segments using the same logic in step 1) above but following each edge transition first left and then right.
- 3) Search among the saved line A1 segments for pairs of line segments that meet the following four criteria:
 - i) If the two lines have the same p1 to p2 directions, verify that the closer of the interline p1 to p2 distances is less than g_{max} . If the two lines have opposite p1 to p2 directions, verify that the closer of the interline p1 to p1 or p2 to p2 distances is less than g_{max} .
 - ii) Verify that the two lines are co-linear within 5 degrees.
 - iii) Verify that the two lines have the same saved colour if their p1 to p2 directions are the same or that the saved colours are opposite if their p1 to p2 directions are opposite to each other.
 - iv) Form two temporary lines by extending each line to reach the point on the extension that is closest to the furthest end point of the other line segment. Verify that the two extended lines are separated by less than $0,5m_{min}$ at any point between the two extended lines.
- 4) For each pair of lines meeting the criteria of step 3) above, replace the pair of line segments with a longer A1 line segment that is a "best fit" line to the four end points of the pair of shorter line segments. Also save the colour of the left side of the edge of the new longer line viewed from its p1 endpoint to its p2 endpoint.
- 5) Repeat steps 3) and 4) until no more A1 line pairs can be combined.
- 6) Select line segments that are at least as long as d_{min} . Flag them as "L" side candidates.
- 7) Look for pairs of "L" side candidates that meet the following three criteria:
 - i) Verify that the closest points on each line are separated by less than $1,5g_{max}$.
 - ii) Verify that they are perpendicular within 5 degrees.
 - iii) Verify that the same saved colour is on the inside of the "L" formed by the two lines. Note that if one or both lines extend past their intersection, then the two or four "L" patterns formed will need to be tested for matching colour and maintaining a minimum length of d_{min} for the truncated side or sides before they can become "L" candidates.
- 8) For each candidate "L" pair found in step 7) form an "L" candidate by extending the segments to their intersection point.
- 9) If the "L" candidate was formed from line segments with the colour white on the inside of the "L", form a colour inverted image to decode. Attempt to decode the symbol starting with the appropriate normal or inverted image starting from step d) below using each of the "L" candidates from step 8) as the "L" shaped finder. If none decode, proceed to step c).
- c) Maintain the line A1 line segments and "L" side candidates from the previous steps. Continue searching for "L" candidates using horizontal and vertical scan lines offset from previous scan lines:
 - 1) Using a new horizontal scan line $3m_{min}$ above the centre horizontal scan line, repeat the process in step b)1), except starting from the offset from the centre point, and then b)3) through b)9). If there is no decode, proceed to the next step.
 - 2) Using a new vertical scan line $3m_{min}$ left of the centre vertical scan line, repeat the process in step b)2), except starting from the offset from the centre point, and then steps b)3) through b)9). If there is no decode, proceed to the next step.

- 3) Repeat step 1) above except using a new horizontal scan line $3m_{min}$ below the centre horizontal scan line. If there is no decode, repeat step 2) above except using a new vertical scan line $3m_{min}$ right of the centre vertical scan line. If there is no decode, proceed to step 4) below.
 - 4) Continue processing horizontal and vertical scan lines as in steps 1) through 3) that are $3m_{min}$ above, then left, then below, then right of the previously processed scan lines until either a symbol is decoded or the boundary of the image is reached.
- d) First assume that the candidate area contains a square symbol. If the area fails to decode as a square symbol, then try to find and decode a rectangular symbol starting from procedure j). For a square symbol, first plot a normalised graph of transitions for the equal sides of the candidate area in order to find the alternating module finder pattern:
- 1) Project a line through the candidate area bisecting the interior angle of the two sides of the "L" found above as shown in figure 9. Define the two equal areas formed by the bisecting line as the right side and the left side as viewed from the corner of the "L".
 - 2) For each side, form a line called a "search line" between a point d_{min} distance from the corner along the "L" line, parallel to the other "L" side line, and extending to the bisecting line as shown in Figure 9.
 - 3) Move each search line away from the corner of the "L" as shown in Figure 9, lengthening each line as it expands to span its two bounding lines, the "L" line and the bisecting line. Keep each search line parallel to the other "L" side line. As each side is moved by the size of an image pixel, count the number of black/white and white/black transitions, beginning and ending the count with transitions from the colour of the "L" side to the opposite colour. A transition from one colour to the other is to be counted only when the current search line as well as the search lines immediately above and below have the same colour, opposite to the previously counted transition colour. Plot the number of transitions multiplied by the length of the longest "L" side divided by the current length of the search line measured between the two bounding lines:

$$T = (\text{number of transitions}) ("L" \text{ max. line length}) / (\text{search line length}).$$

This formula normalises T to keep it from increasing because the line lengthens.

Continue to calculate the T values until the search line is longer than the longest axis of the candidate area plus 50%.

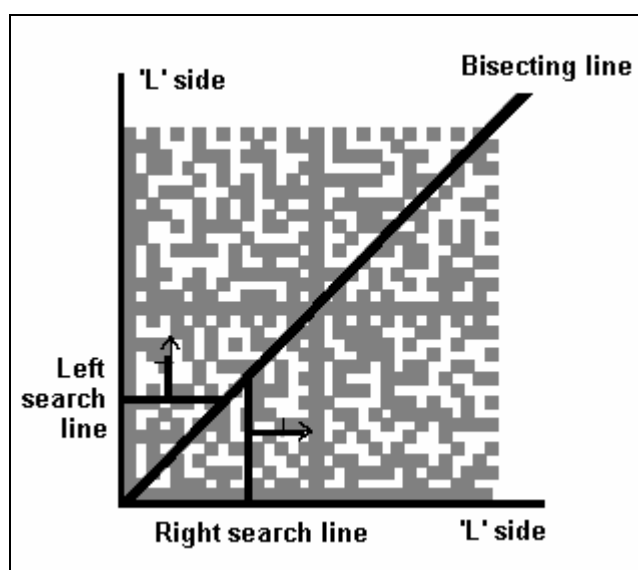


Figure 9 — Expanding search lines

- 4) Form a plot of the T values for each side, where the Y-axis is the T value and the X-axis is the search line's distance from the corner of the "L". A sample plot is shown in Figure 10.

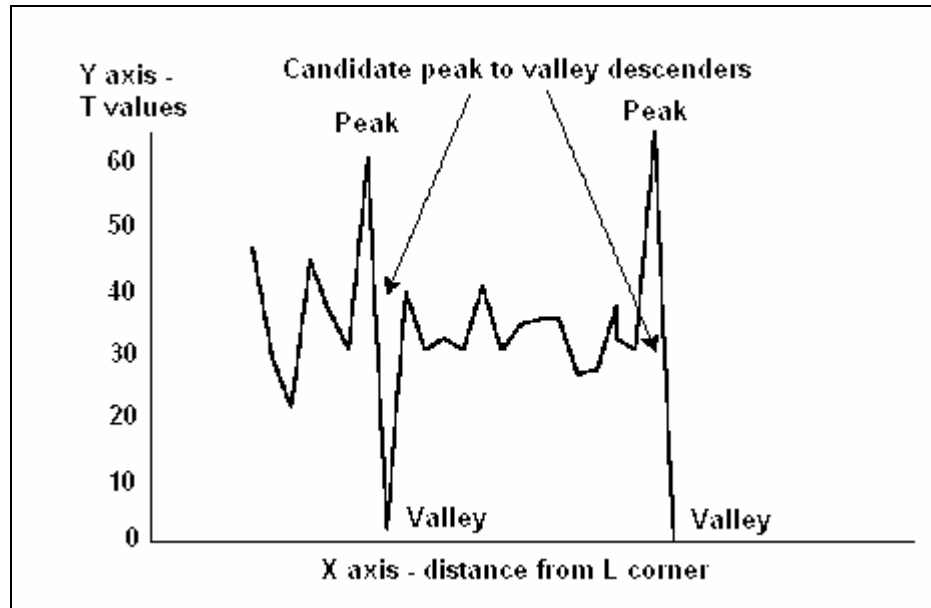


Figure 10 — Example plot of T as the search line expands

- 5) Starting from the T value with the smallest X in the right side's plot and then increasing X , find the first instance of a T_s value ($T_s = \text{maximum of zero and } T - 1$) that is less than 15% of the preceding local maximum T value, provided that T value is greater than 1. Increment this X value until the number of transitions stops decreasing. If the number of transitions does not increase, increment the X value once more. Refer to this X value as the valley. Increment the local maximum's X value until the number of transitions decreases and refer to this X as the peak. Refer to the average of the peak and valley X values as the descending line X value. The search line at the peak may correspond to an alternating finder pattern side. At the valley, the search line may correspond to the solid dark interior line or a light quiet zone.
 - 6) Find the peak and valley in the left side's plot whose descending line X value most closely matches the right peak and valley's descending line X value. If returning to this step from a later step, consider additional left peaks and valleys, ordered in terms of how closely they match the right peak and valley. However, any left peak and valley under consideration must be checked to ensure that the absolute difference between the right and left peak X values is less than 15% of the average of the two peak X values and that the absolute difference between the right and left valley X values is less than 15% of the average of the two valley X values. The 15% specifies the maximum allowed foreshortening.
 - 7) The right side's valley search line, the left side's valley search line, and the two sides of the "L" outline a possible symbol's data region. Process the data region according to step e). If the decode fails, find the next left peak and valley from step d)6). Once all left peaks and valleys have been discarded, discard the right side peak and valley and continue searching from step d)5) for the next right peak and valley.
- e) For each of the two sides of the alternating pattern, find the line passing through the centre of the alternating light and dark modules:
- 1) For each side, form a rectangular region bounded by the side's peak and valley search lines as the longer two sides of the rectangle, and the "L" side and the other side's valley search line as the shorter two sides, as shown in Figure 11.

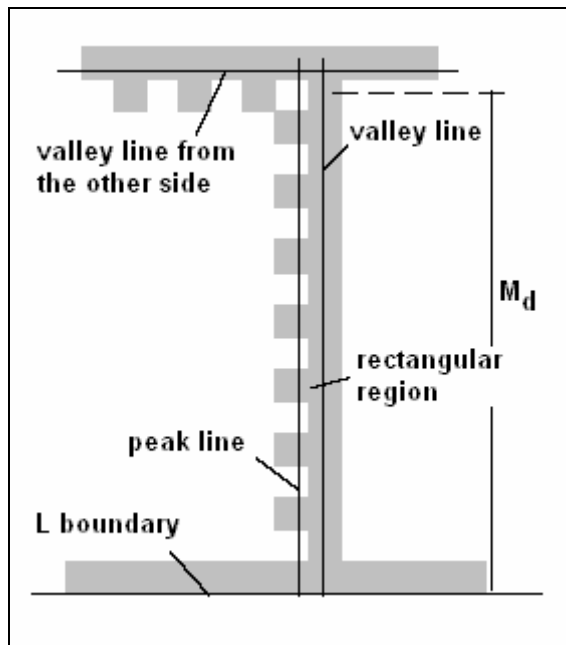


Figure 11 — Rectangular region construction

- 2) Within the rectangular region, find pixel edge pairs on the outside boundary of teeth:
 - i) Traverse test lines starting with and parallel to the valley line looking for transitions to the opposite colour normally orthogonal to the test line. Select only transitions that are either dark to light or light to dark where the first colour matches the predominate colour of the image along the valley line.
 - ii) If the number of transitions found is less than 15% of the number of pixels comprising the valley line, and the test line is not the peak line, move the test line toward the peak line by nominally one pixel and repeat step i), now considering new transitions in addition to those already found. If the 15% criterion is met or the peak line is reached, continue to the next step, otherwise continue searching from step d)6) for the next left peak and valley.
 - iii) Calculate a preliminary "best fit line" with linear regression using the points on the edge between the selected pixel pairs.
 - iv) Discard the 25% of the points which are furthest from the preliminary "best fit line". Calculate a final "best fit line" with linear regression using the remaining 75% of points. This line should pass along the outside of the alternating pattern, shown as the "best fit line" in Figure 12.
- 3) For each side, construct a line parallel to the step e)2) line which is offset toward the "L" corner by the perpendicular distance from the "L" corner to the peak search line divided by twice the number of transitions in the peak search line plus one:

$$\text{Offset} = \text{distance to the peak line} / ((\text{number of transitions} + 1) * 2)$$

Each of the two constructed lines should correspond to the mid-line of the alternating module pattern on that side, see Figure 12.

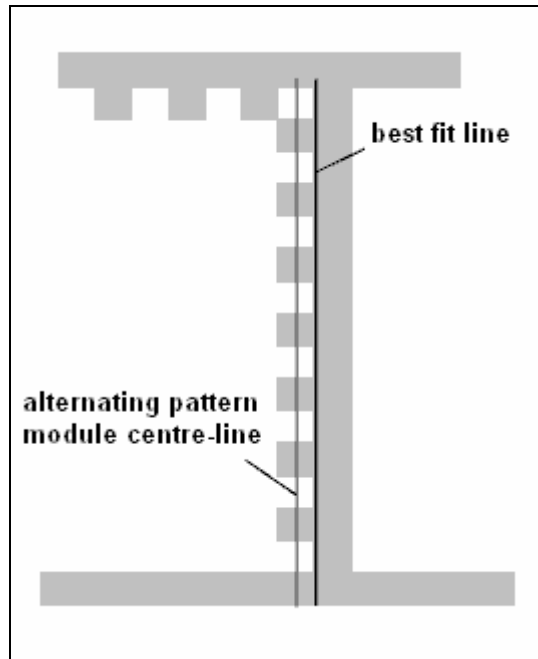


Figure 12 — Alternating pattern module centre-line

- f) For each side, measure the edge-to-edge distances in the alternating pattern:
- 1) Bound the alternating pattern mid-line constructed in step e)3) by the adjacent “L” line and the other alternating pattern mid-line from step e)3). Call the length of this line M_d (see Figure 11).
 - 2) Along the bounded mid-line, measure the edge-to-edge distances between all the similar edges of all two-element pairs, i.e. dark/light and light/dark element pairs. Begin and end the edge-to-edge measurements with edges transitioning from the “L” colour to the opposite colour.
 - 3) Select the median edge-to-edge measurement and set the current edge-to-edge measurement estimate, EE_Dist , to the median measurement.
 - 4) Discard all element pairs with edge-to-edge measurements that differ more than 25% from EE_Dist .
- g) For each side, find the centre points of the alternating pattern modules:

- 1) Using the remaining element pair measurements from f)4), calculate the average ink spread (vertical or horizontal depending on the segment side) by the average of the element pair’s ink spread, where bar is the dark element width and $space$ is the light element width in a remaining element pair:

$$ink_spread = \text{Average} ((bar - ((bar + space) / 2)) / ((bar + space) / 2))$$

- 2) Calculate the centre of the bar in the median element pair using the following offset into the bar from the outside edge of the bar in the median pair:

$$offset = (EE_Dist * (1 + ink_spread)) / 4$$

If there is more than one median element pair, choose a single pair using the following process:

- i) Order the edges (excluding the “L” finder edge) by their distance from the “L” finder edge. There are an odd number of these edges because the edges start and end on a dark to light transition going away from the “L” finder.
- ii) Call the middle edge in the list the centre edge.

- iii) Calculate the (odd number of) element pair edge-to-edge distances and find their median EE_Dist .
 - iv) Select the one or more element pairs with length EE_Dist .
 - v) Among those pairs identify the one or two element edge pairs that has an edge closest to the centre edge.
 - vi) If there is still a tie, take the element pair that has the outer edge of the bar closest to centre edge.
 - vii) If there is still a tie, take the element pair that has an inner edge closest to the “L” finder.
- 3) Starting from the centre of the bar in the median element pair from step f)3) proceed in the direction of the space in the element pair until reaching the end of the bounded mid-line, calculate each element's centre, shown by the speckled pattern in Figure 13, by the following steps:

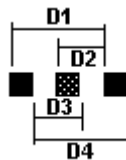


Figure 13 — Edge-to-edge measurements for finding an element centre

(While three bars and two spaces are shown in Figure 13, if a space is the element for which the centre is to be calculated, then the diagram would have three spaces instead of the bars and two bars instead of the spaces. For light elements adjacent to the element at the end of the mid-line, either $D1$ or $D4$ measurements are omitted as they would fall outside the symbol's or segment's measurable element boundaries.)

- i) Calculate a point $p1$ along the mid-line which is $EE_Dist/2$ from the previously calculated element centre in the direction of the new element.
- ii) Calculate d_1 through d_4 where:

$$d_1 = D1 / 2$$

$$d_2 = D2$$

$$d_3 = D3$$

$$d_4 = D4 / 2$$
- iii) If one of the values d_1 through d_4 is within 25% of EE_Dist , select the one which is closest to EE_Dist , and set the new EE_Dist to be the average of the current EE_Dist and the selected d_1 through d_4 distance.
 - I) If d_1 or d_4 are selected, select the corresponding $D1$ or $D4$ edge closest to the element, the centre of which is to be calculated. Offset this edge by $(ink_spread/2) * (EE_Dist/2)$ in the appropriate direction (i.e., if ink_spread is positive, the offset will move the edge toward the space included in the distance $D1$ or $D4$ and if negative, the offset will move away from this space). Calculate a point $p2$ along the mid-line which is 0,75 times the selected d_1 or d_4 value from the offset edge and toward the element centre to be calculated.
 - II) If d_2 or d_3 are selected, select the corresponding $D2$ or $D3$ edge closest to the element the centre of which is to be calculated. Offset this edge by $(ink_spread/2) * (EE_Dist/2)$ in the appropriate direction (i.e., if ink_spread is positive, the offset will move the edge toward the space included in the distance $D2$ or $D3$ and if negative, the offset will move away from this space). Calculate a point $p2$ along the mid-line which is 0,25 times the selected d_2 or d_3 value from the offset edge and toward the element centre to be calculated.

- III) Set the element's centre as halfway between p_1 and p_2 .
- iv) Otherwise if none of the values d_1 through d_4 is within 25% of EE_Dist , leave EE_Dist at its current value, use p_1 as the new element's centre, and proceed to the next element.
- 4) Starting from the bar in the median element pair, and proceeding in the opposite direction from step 3), until reaching the other end of the bounded mid-line, calculate each element's centre, following the procedures in step 3).
- h) If the number of modules in each side do not correspond to a valid first region, continue searching from step d)6) for the next left peak and valley. Otherwise plot the data module sampling grid in the data region by extending the alternating pattern module centres:
 - 1) Extend each side's step e)3) mid-line and the opposite side's "L" line to form the vanishing point of the two nearly parallel or parallel extended lines.
 - 2) Extend rays from each vanishing point passing through the step g) module centres of the nearly perpendicular step e)3) line.
 - 3) The intersection of the two sets of nearly perpendicular rays should correspond to the centres of the data modules in the data region, as shown in Figure 14.

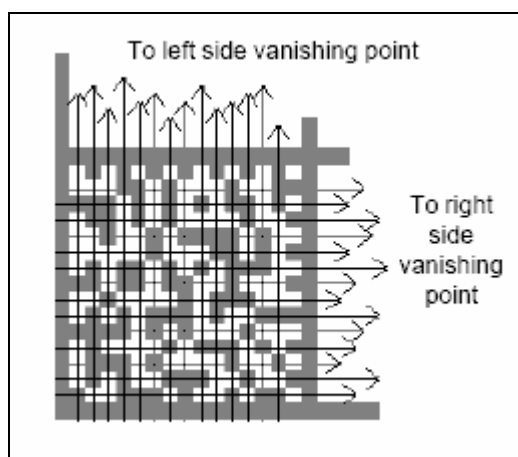


Figure 14 — Module sampling grid construction

- i) Continue to fill in the remaining data regions:
 - 1) When a data region is processed, form a new "L" for the next data section to the "left" or "above" using one of two processes:
 - i) If the new data region is still bounded on one side by the original "L" from procedure b), repeat from procedure c) to process the new data region using the selected set of points from step e)2) and the set of points on the "L" from step b)2) which lie beyond the step e)2) line.
 - ii) If the new data region is bounded on two sides by data regions, repeat from procedure c) to process the new data region using the selected set of points from step e)2) for each data region which are adjacent and bound the new region on two sides
 - 2) If a data region does not match the number of modules in previously processed regions, trim the symbol to the largest number of regions which correspond to a legal symbol.
 - 3) Decode the symbol with its one or more data regions starting with procedure k).

- 4) If the current data region exhausts its last peak and valley, revert to the previous data region and continue searching from step d)6) for the next left peak and valley in that data region.
- j) Find the data sections of a rectangular symbol.
- 1) For each side of the "L" move a line perpendicular to the side and scanning along the length of the other side of the "L". Keep each search line parallel to the other "L" side line. As each side is moved by the size of an image pixel, count the number of black/white and white/black transitions, beginning and ending the count with transitions from the colour of the "L" side to the opposite colour. A transition from one colour to the other is to be counted only when the current search line as well as the search lines immediately above and below have the same colour, opposite to the previously counted transition colour. As each side is moved by a pixel, plot the number of transitions, T . Continue until the parallel line moves further than the perpendicular leg of the "L" plus 10%.
 - 2) Starting from the origin of the plot, for each direction, find the first instance of a T_s value (T_s = maximum of zero and $T - 1$) value that is less than 15% of the preceding local maximum T value, provided that T value is greater than 1. Increment this X value until the T value stops decreasing. If the T value does not increase, increment the X value once more. Refer to this X value as the valley. Increment the local maximum's X value until the T value decreases and refer to this X as the peak. Refer to the average of the peak and valley X Values as the descending line X value. The valley line at this point may form a side of a symbol or data region.
 - 3) Find the alternating pattern lines for each side of the region similar to procedure e).
 - 4) Plot the module sample grid in the data region or symbol as in procedures f), g), and h).
 - 5) If the data region defined is not a valid rectangular symbol, try to form a new data region using further valid peak to valley plot transitions.
 - 6) Process any additional regions as in procedure i).
 - 7) If a valid data region or two regions are detected, attempt to decode the symbol as in procedures k) and l). If the region(s) were not valid or the decode fails, disregard the candidate area.
- k) If the number of data modules is even or the symbol forms a valid rectangular symbol, decode the symbol using Reed-Solomon error correction:
- 1) Sample the data modules at their predicted centres. Black at the centre is a one and white is a zero.
 - 2) Convert the eight module samples in the defined codeword patterns into 8-bit symbol character values.
 - 3) Apply Reed-Solomon error correction to the symbol character values.
 - 4) Decode the symbol characters into data characters according to the specified encodation schemes.
- l) Otherwise the number of data modules is odd, so decode the symbol using convolution code error correction:
- 1) Sample the data modules at their predicted centres. Black at the centre is a one and white is a zero.
 - 2) Apply the black/white balancing mask.
 - 3) Use the bit ordering table to convert the data into a bit stream.
 - 4) Apply the appropriate convolution code error correction.
 - 5) Convert the bit stream to data characters according to the encodation scheme specified.
 - 6) Verify that the CRC is correct.