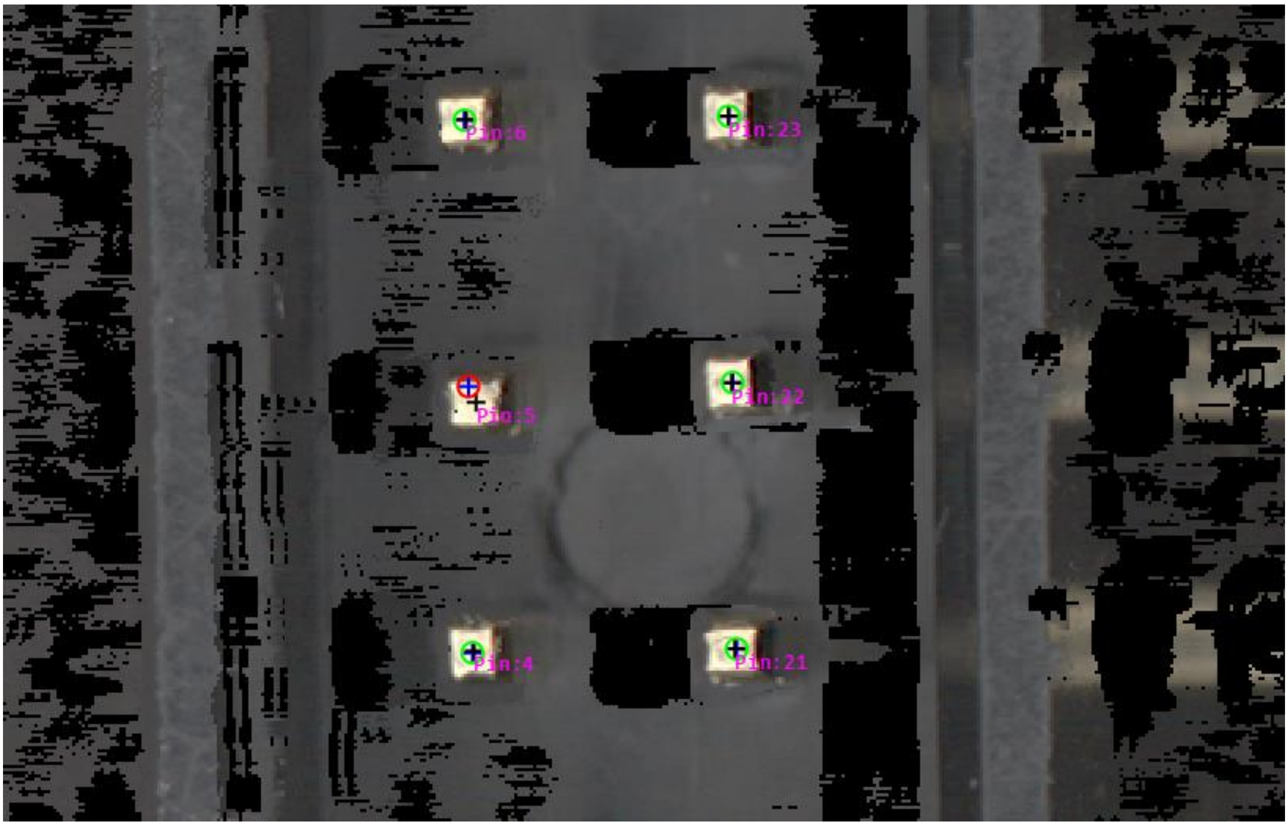
Connector pin inspection

Application report



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Content

1. Measurement task:

Especially in the automotive industries the quality of every single electrical connector is of utmost importance to ensure safety and reliability of modern vehicles. To allow for high volume and cost-effective production on the other hand, a fully automated test must be applied to every single connector. In the following we propose a suitable concept based on optical methods, employing a Chromasens 3DPIXA high speed stereo line scan camera in combination with a sophisticated image data processing pipeline. The main task is to measure the relative position of pin tips to each other and also absolute with respect to the connector housing. Therefore the applied image processing algorithm must detect a various number of plugs in the image and create corresponding regions if interest. The pin tips of a plug have to be in a predefined grid with cylindrical areas. The algorithm must define this reference grid and align this grid to the pin tips. The aim of the measurement is to detect individual pins that are not in this area. These pins could cause contact problems, the plugs must be sorted out.

This report is an example how to use a 3DPixa and the 3DAPI to implement a measuring task for connectors.

2. Scanning environment

The measurement task is solved with the following components.

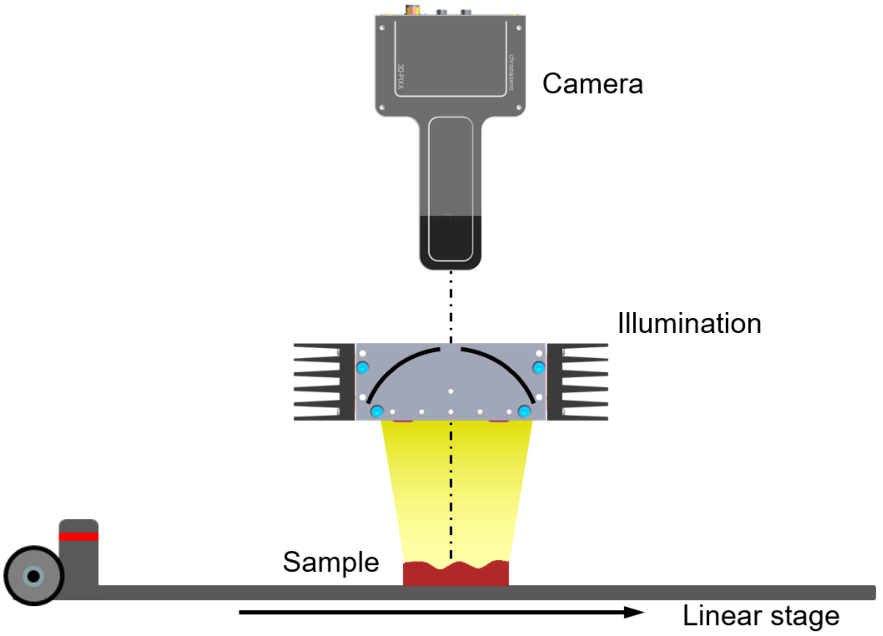
- **3DPIXA** **CP000470-D01-030-105**
  - Optical resolution: 30µm
  - Height range: 8.2mm
  - Field of view: 105mm

- **Corona II** **CP000200-170T-04-XXXX**
  - Tube light for diffuse lightning situation
  - Length: 170mm
  - XXXX → Cable length and cooling solution

- **XLC4** **CP000411**

- **Software**
  - 3D API Version 3.1
  - Halcon Version 18.11 Progress

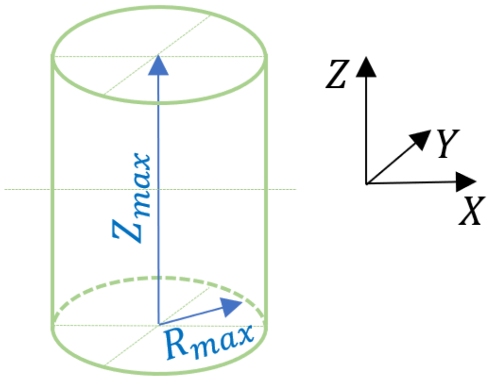
The test setup is illustrated schematically below. The camera and the illumination are aligned rectangular to the surface of the plugs. The background is a black, nonreflecting paper. This makes is easier to detect the position and alignment of the plugs.



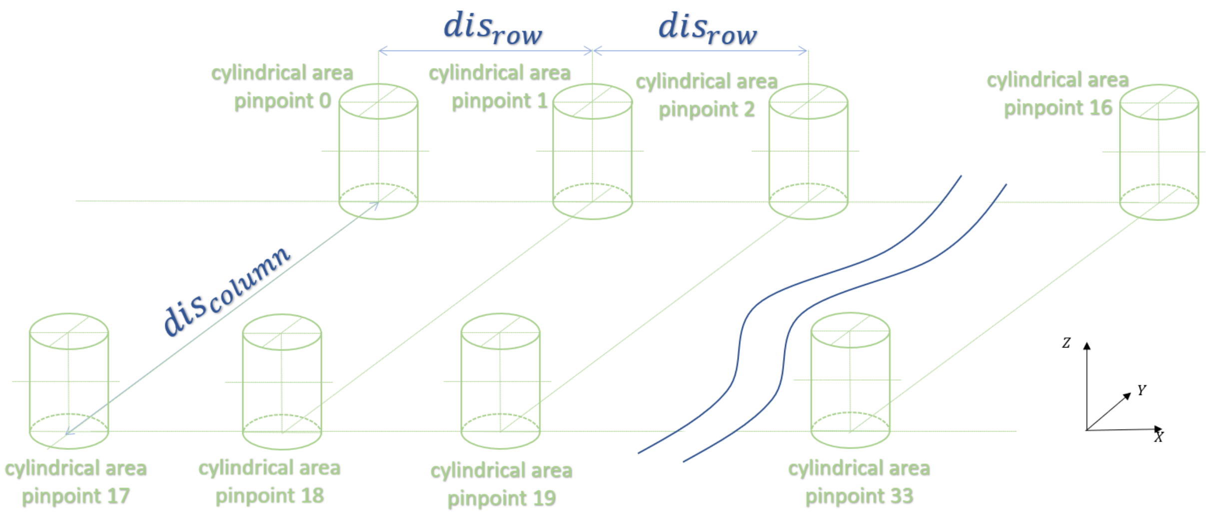
The best focus plane of the camera in this case is the average height of the pin tips. For measurement tasks that include the plug bottom (measurement of pin height) a good sharpness of the pin tips and a sufficient sharpness of the plug bottom is necessary. The best measurement plane would be slightly below the pin tips. There are multiple images with plugs that are manually positioned with a different alignment. All plugs are aligned so that the long side is approximately parallel to the transport direction.
The plugs have 34 pins. The plug housing is made of reflective black plastic. If the floor of deep connector housings needs to be measured as reference, the Corona coaxial light module is recommended. Due to the parallel beam path the its possible to illuminate deep structures without shadows.

3. Definition and alignment of the reference grid

Aim of the measurement is to ensure that every pin is in a permitted volume. In this case this volume is a cylinder. The radius of the cylinder determines the permitted area in the xy-plane. The height of the cylinder defines the third dimension.

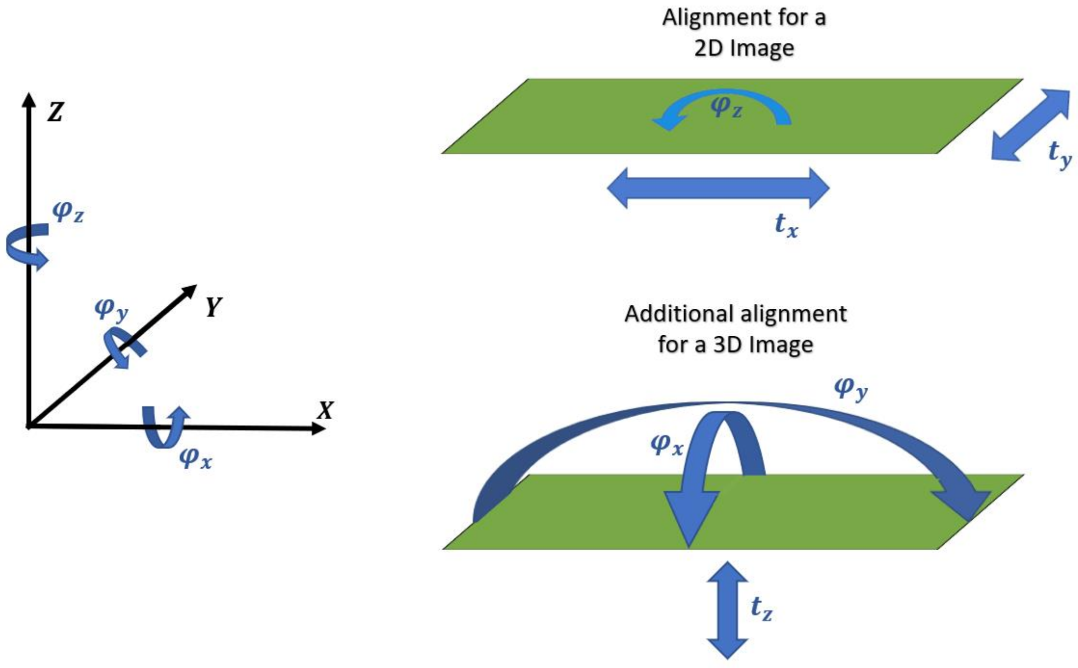


In this case the plug has 34 pins arranged in 2 columns and 17 rows. Depending on the target dimension the distance between the cylindrical areas must be defined in row and column direction (dis_{row} and dis_{column}).



For the alignment of the reference grid there is no fixpoint in this case. This has the consequence, that the pins are only measured relative to each other. The advantage is that there is no need for a fixed point, which itself can be faulty. A disadvantage is that the algorithm does not control the absolute position of the pins. Which measurement method is used has to be decided for each new measurement task.

Due to the 3D measurement task the grid must be aligned in coordinate space with 6 degrees of freedom.



Halcon[1] provides various functions for 2D and 3D transformations. In this case a function is used that approximates a 3D transformation from point correspondences and returns it as the transformation matrix. This means, the function calculates a transformation matrix from two coordinate sets. The first coordinate set is the reference grid in in the origin of the global coordinate system, the second set are the coordinates of the measured pin tips.
The function allows different types of transformation. With the parameter 'rigid' a rigid transformation is calculated. This means that just rotation and a translation is permitted. Scaling is not allowed

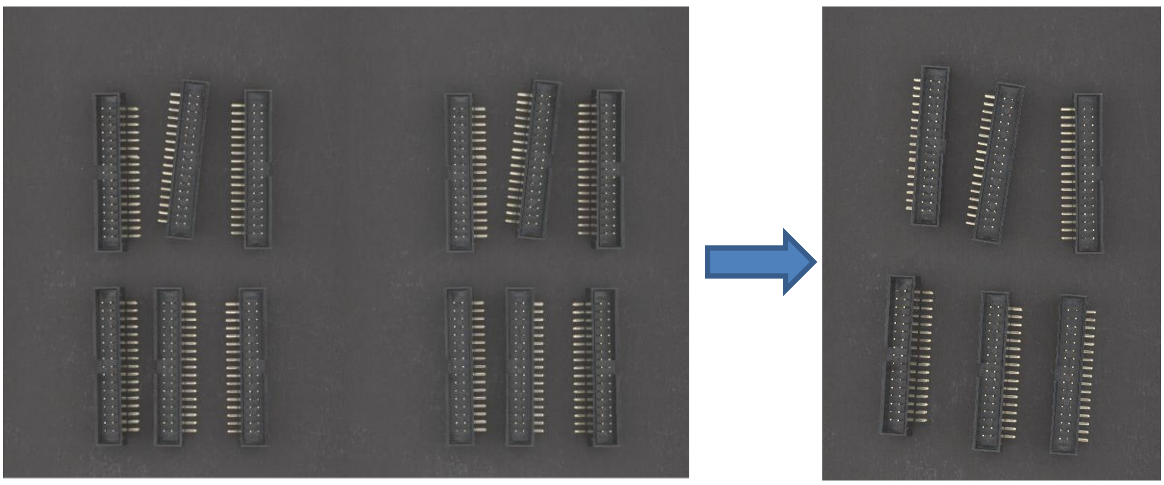
4. Measurement Approach

The measurement Task consists of multiple subtasks that are described in the following sections.

1) **Load and rectify image.**
   After loading the image in Halcon the CS-API is used to rectify the images and generate the height data. Distortion and other image errors are corrected in the rectified image. The Height data is needed later to calculate the z-position of the pin tips.
   To use the CS-API the following steps have to be done:
   a. Create a Halcon handle - *"create_cs_3d_handle"*
      A Handle is an Halcon instance of the CS-API. With a single license dongle only one instance can be opened at the same time. This includes instances in other applications like the CS-3D-viewer.

[1] https://www.mvtec.com/

b. Load the configuration – *“cs_3d_load_config_from_file”*
   This function sends the camera and calibration parameter of the camera to the CS-API. Make sure that the correct file is loaded.
c. Set the calculation parameters – *“cs_3d_set_param”*
   This function determines the calculation parameters for the 3D calculation. The best way to figure out these parameters is to use the CS 3D Viewer.
   The most important parameters are:
   - *'height_range_start_in_px'* -e.g. -17
   - *'height_range_end_in_px'* -e.g. 23
   - *'min_correlation_score'* -e.g. 0.4
   - *'window_type'* -e.g. '15x15'
d. Load the image - *“cs_3d_acquire_image”*
   This function loads the image. The image have to be loaded before the calculation can be started.
e. Do the 3D calculation - *“cs_3d_stereo”*
   This function calculates the 3D data. The result depends on the settings in the configuration file. In this case the 3D point cloud is not necessary and can be deactivated (*“doCalc3DPoints”* = 0). The option *“enableCombinedView”* generates rectified images which are not suitable for image processing, therefore this option must be deactivated. Both rectified images (A and B) are needed in this case. The option “*doCalcRectifiedImageB*” must be activated.
f. Get additional results - *“cs_3d_get_result”*
   This function allows access to further results. In this case the rectified image B.

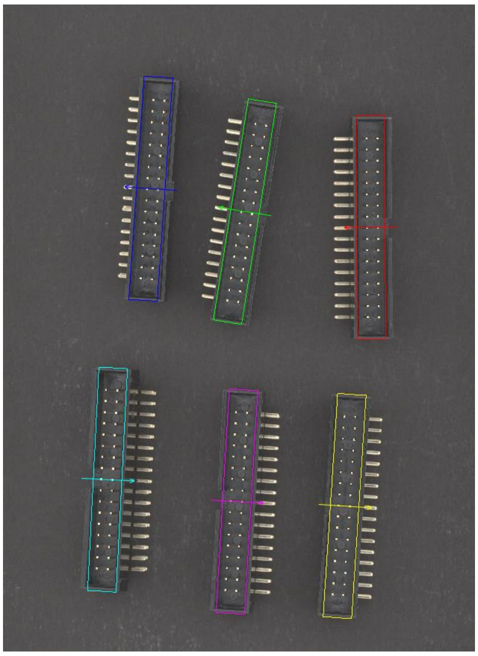


Raw image AB

Rectified image A

2) **Find the plugs in the image with a shape model.**
   There are multiple plugs with a various orientation in every image. To find these plugs and determine position and alignment a shape model matching is used. Therefore a shape model must be created once with an image of an random plug. A Halcon algorithm finds all plugs in the image with this shape model. As output information this algorithm provide the position and

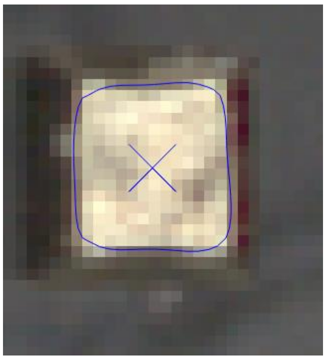
orientation of the plugs. For runtime and stability reasons the shape model search is just applied in the rectified image A. For the position in the image B an offset value is added to the result of the image A. The parameters to generate a ROI don't have to be very accurate.



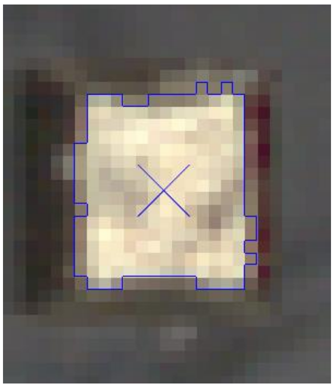
3) Create a ROI for every plug
   The following steps are done for each plug found, in a for-loop. With the information of the shape matching algorithm a ROI for the plug is created. The ROI covers the area in which the pin tips are expected. This step has to be performed for both images A and B.

4) Find the pin tip center
   Also this step must be performed for the images A and B.
   To find the center of the pin tip there are multiple solution approaches. In the following there are shown two ways.

a. XLD contour
With an edge finder algorithm it is possible to generate subpixel precise XLD contours. This XLD contours are sorted and connected. A criterion for sorting out invalid XLD contours can be the length of the contour. In a final step the contours are closed to a closed shape. It is possible to calculate the area center of closed shapes. The area center of this shape represents this center of the pin tip.

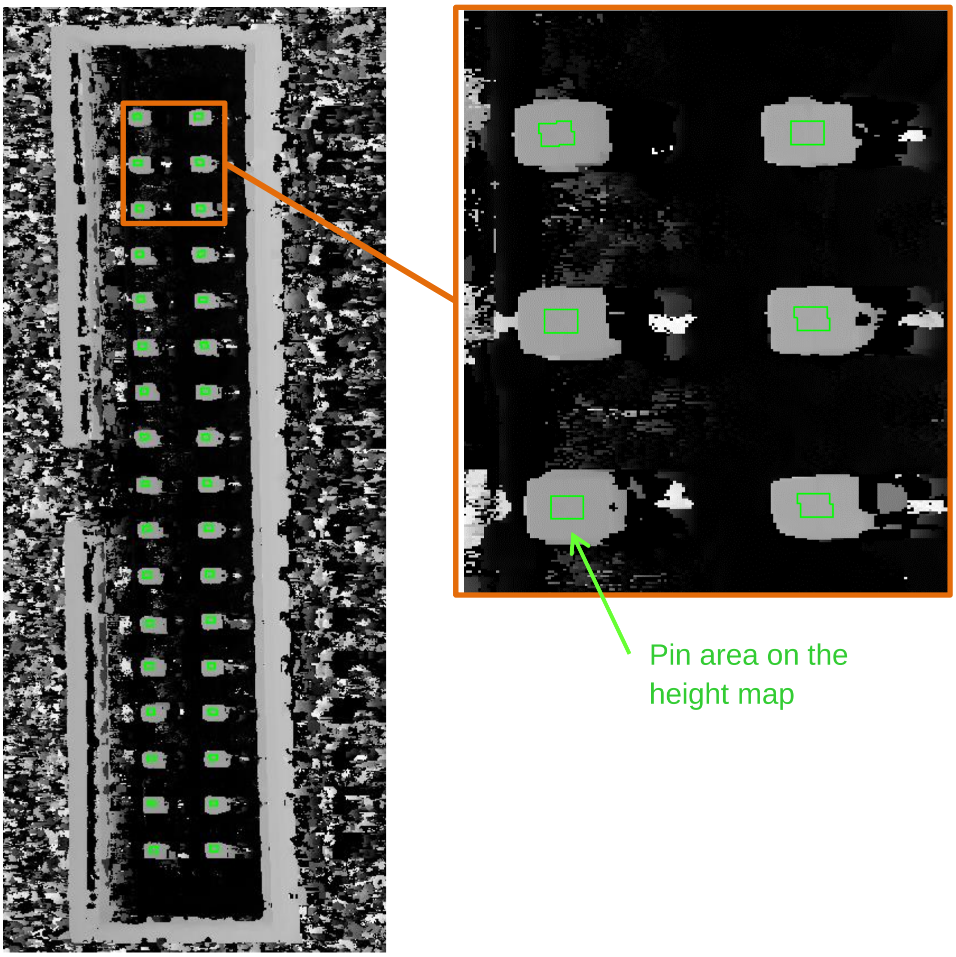



b. Gray value threshold
The pin tips are much brighter than the plug bottom. This property can be used to detect the pin tips with a gray value threshold. The regions found that do not belong to a pin can be sorted out with further algorithms. Criteria for sorting out invalid regions can be the area or the compactness. The center of the pin tip can be defined as the center of area of the region that represents a pin.

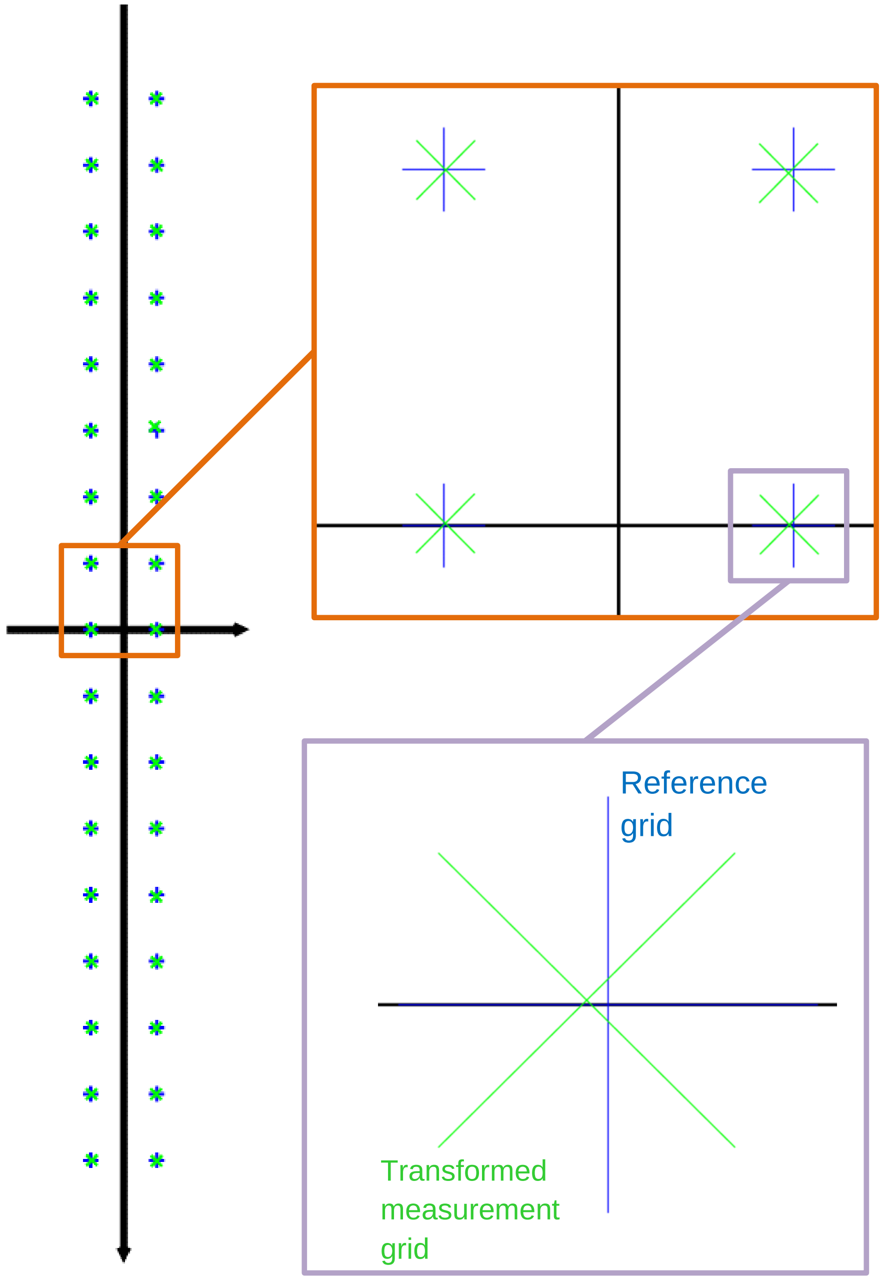



5) Sort the pin tip center coordinate pairs.
Depending on the alignment of the plugs, the coordinate pairs (row/column) of the pin tips are arranged in a random order. To compare them with the reference gird (see section 3) the coordinates must be in the predefined order. The first step to achieve this predefined order is to apply a rotative 2D transformation matrix on the coordinate pairs. The rotation angle is known from the shape model matching. The rotated coordinate pairs are independent of the plug alignment. This ensures that the coordinate pairs of all plugs are comparable. After this there are two datasets with pin tip center, the original and the rotated one. The rotated one is used in the following steps to sort both datasets.
The first sorting step is to separate the pins in two groups representing the column. The pins on the side with the feet of the plug belong to the group “feet side”. These are the pins with the column value that is larger than the average of all column values. The numbers 18 to 33 are assigned to this group in an order ascending with the row value. The other pins belong to the group “opposite side”. The numbers 0 to 17 are assigned to this group in an order ascending with the row value.
The coordinate pairs of the pin tips of the images A and B must be sorted in the same way.
6) Calculate the perspective corrected coordinates
The resolution of the optic system changes with the distance of the object as the beam path widens conically. This causes measurement errors. Because the 3D data is known, the 3D-API is able to compensate this error. This is called perspective correction or central view. With the parameter “*enableCombinedView*” in the config file its possible to calculate a rectified perspective corrected image. Due to the perspective correction, the image will contain some artefacts. These artefacts can complicate image processing tasks like edge detection or segmenting areas with thresholds and filter functions. Therefore, in this example the rectified image without perspective correction is used for these tasks.
The perspective error which is caused by working with the not perspective corrected images can be compensated with the function *“cs_3d_rectimagecoords_to_perspectivecorrectedrectcoords*”. This function expects corresponding coordinate pairs of the image A and B. The output is a perspective corrected coordinate pair.

7) Height measurement
For the height measurement of the pins a small area in the middle of each pin tip is selected. This area represents the highest part of each pin. The median grey value of this area represents the pin height. The *“cs_3d_gray_to_mm”* function converts the grey value into a result with the unit mm.



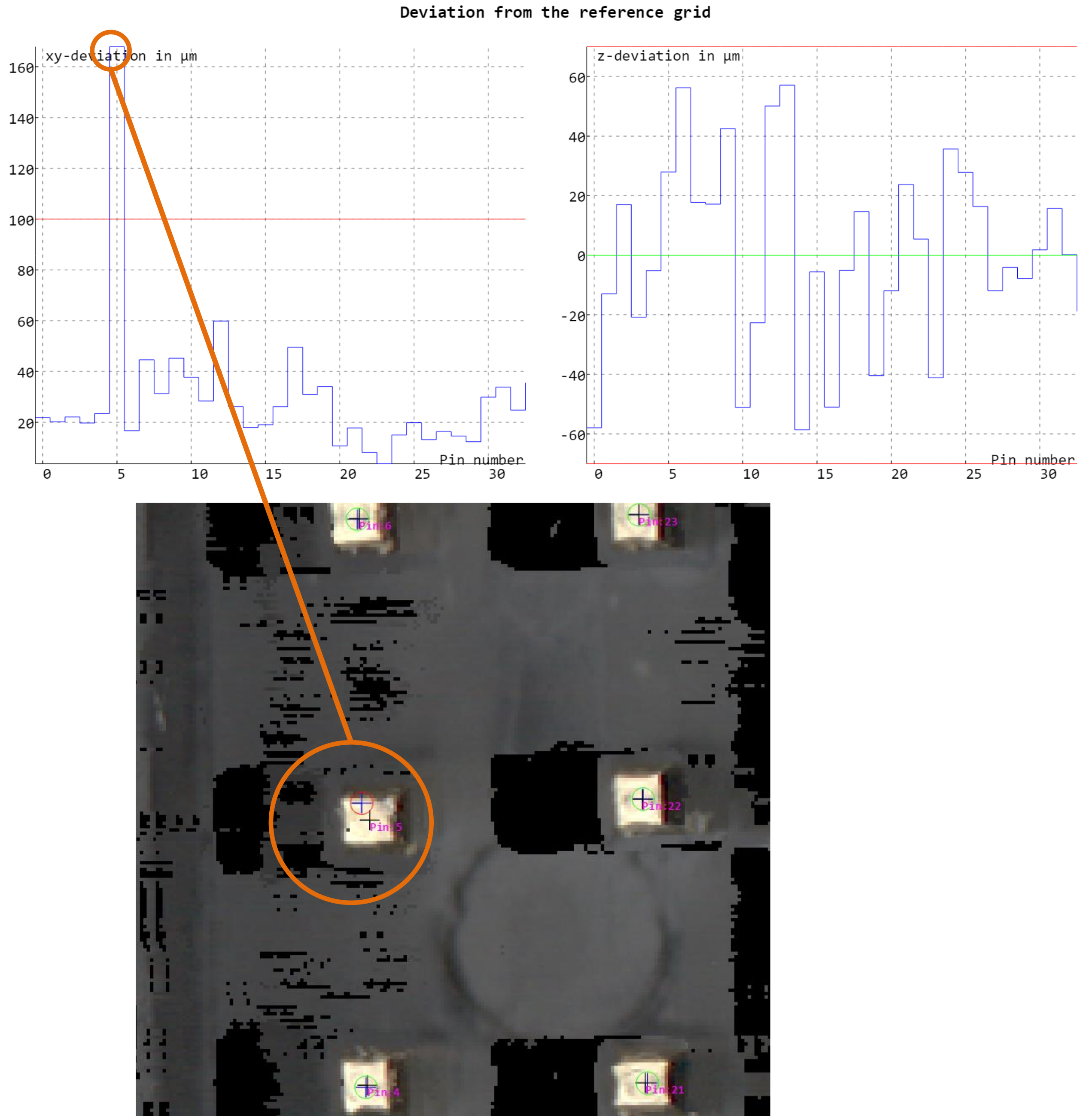
8) Generate the reference grid
The reference grid is a set of x and y and z coordinate point pairs. In a first step the reference grid is defined symmetrical to the origin of the coordinate system. A Halcon algorithm calculates the transformation matrix for which the smallest deviation error results when applied to the measured pin tips (least square errors). In this case the coordinates that represents the pin tips are transformed on the reference grid. This enables to use the standard coordinate system for further steps. It's easy to check whether the pin tips are in the permitted area.
The perspective corrected coordinates of the pin tips are used for this function.



9) Calculate the deviation
To calculate the deviation of the pins to the reference grid, there is only a subtraction necessary. The result in x- and y-direction is in pixels. To get a result in µm the result in pixels has to be multiplied by 30µm/px (camera resolution) because the rectified image is used for the measurement task. To check whether the pin tip is in the permissible circle area of the cylindrical volume the result of the vectoral addition in x- ,y- direction have to be smaller than the permissible radius.

5. Display results

The results are shown in an image and as a diagram.
The graphical result in the image shows the deviation in x- and y- direction. The black crosses represent the measured pin tip centers. The blue crosses represent the fitted reference grid. The circles around the blue crosses are the permissible area in the x-y plane. If the circle is green the pin meets the specification in the xy-plane, if the circle is red, the pin is out of range. In this case the permitted radius is set to 50µm. Pin 5 does not meet this criterion. The permitted deviation in z-direction is ±70µm here. All pins meet these criteria.
The image with the crosses that marks the reference grid and the measured pin tips is the perspective corrected rectified image. This image is only calculated for visualization reasons. If visualization is disabled, this image will not be calculated. The black areas in the image are the artefacts that are caused by the perspective correction.



6. Verify the measurement

Aim of the verification is to calculate the scattering of the results of the measurement. The smaller the scattering is, the better is the evaluation system works. The result of the measurement task is the deviation of a pin tip in x,y and z coordinate form a reference grid. In the following, these deviations are compared for several measurements of the same connector.

6.1 Verification approach

The evaluation of the measurement is separated in the reproducibility and repeatability. For both measurements, a stack of 25 images of the same plug is acquired. To avoid measurement errors due to the thermal behavior of the system, the system (camera and illumination) is switched on 1 hour before the data acquisition starts.

The repeatability measurement evaluates the system with a minimal amount of external disturbance variables. Therefore the plug is positioned one time on the linear stage, after this the 25 images are acquired without repositioning of the plug.

For the repeatability measurement the plug is replaced by hand between every acquisition. The position and alignment changes in every image a little.

To avoid confusion the following designations are introduced:

$$MRxy = xy\ deviation\ of\ the\ pin\ to\ the\ reference\ grid$$
$$MRz = z\ deviation\ of\ the\ pin\ to\ the\ reference\ grid$$

For the statistic evaluation of the result it is not relevant weather the deviation of the pin to the measurement grid is in x, y or z direction. Therefor the designation MR represents all of this results.

$$n = number\ of\ images$$
$$m = varible\ that\ represents\ the\ pins$$

To calculate the standard deviation the MR of the corresponding pins have to be compared. All the following results are arrays with 36 values because the plug has 36 Pins.

In a first step the mean values are calculated:

$$\overline{meanMR_m} = \frac{1}{n} * \sum_{i=1}^{n} \overline{MR_{\iota,m}}$$

The second step is to calculate the variance.

$$\overline{var_m} = \frac{1}{n} * \sum_{i=1}^{n} (\overline{MR_{\iota,m}} - \overline{meanMR_m})^2$$

In the next step the vector with the 36 variances representing each pin of the connector should be reduced to an average value.

$$var := \frac{1}{m} * \sum_{i=1}^{m} \overline{var_m}$$

The standard deviation is the square root of the variance.

$$std = \sqrt{var}$$

The program also determines the greatest deviation from the mean value in both directions. The spread of the measured values is displayed graphically in a measurement value histogram.

6.2 Verification result

In the following part, the verification results are shown and compared with each other. In total there are 4 results. In the code are shown two ways to detect the pin center. Each of these ways is applied for the repeatability and reproducibility measurement.

6.2.1 Repeatability / pin tip center – XLD contour

XY Std = 1.98 µm

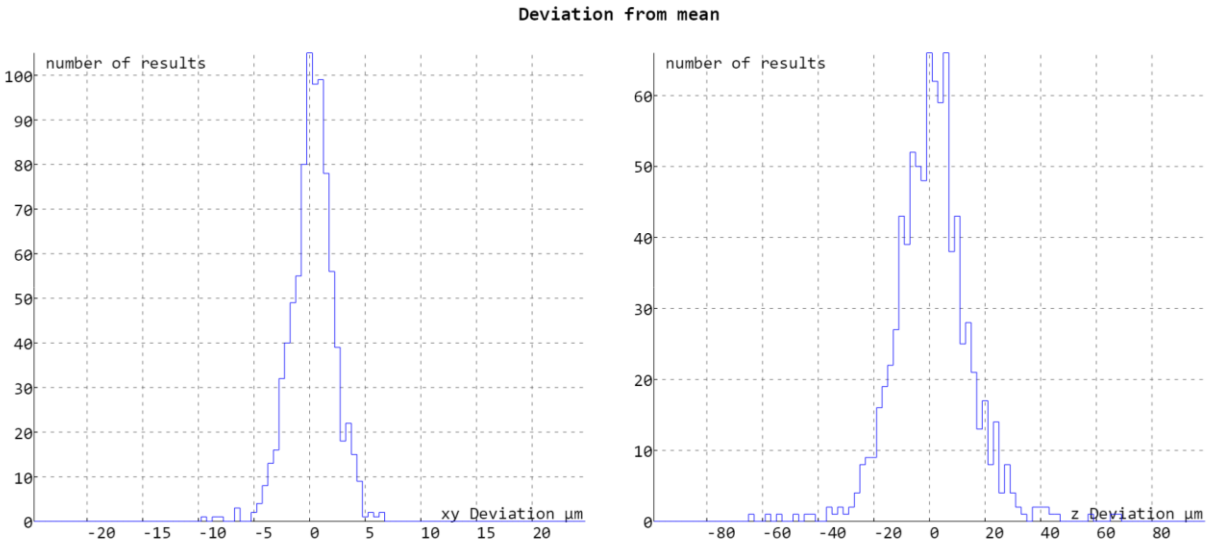
XY dev max = 6.28 µm

XY dev min = -9.66 µm

Z Std = 13.34 µm

Z dev max = 67.94 µm

Z dev min = -65.83 µm



6.2.2 Repeatability / pin tip center – threshold

XY Std = 2.35 µm

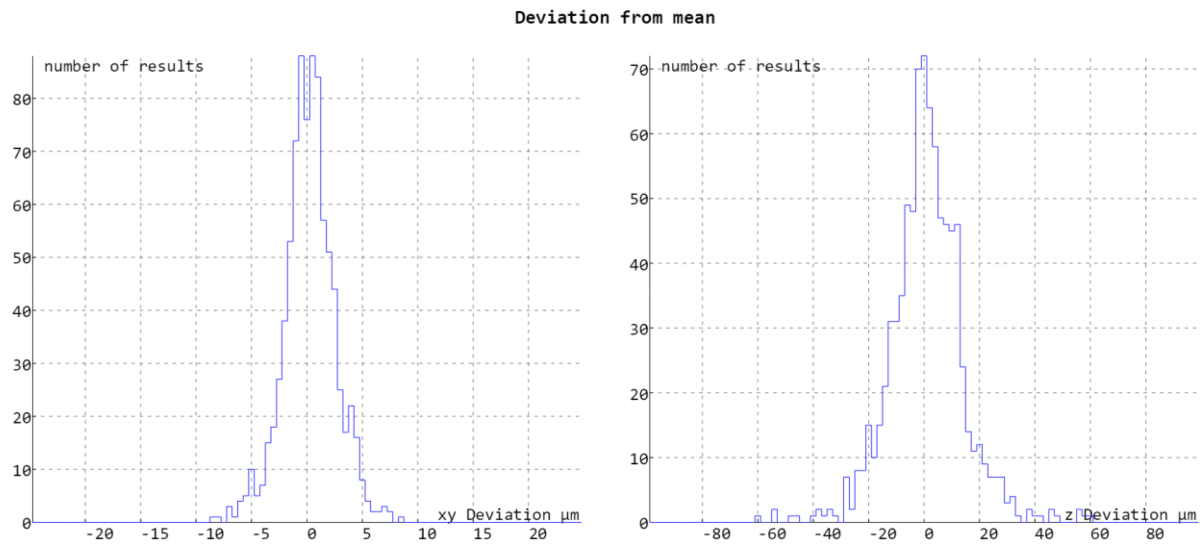
XY dev max = 8.27 µm

XY dev min = -8.83 µm

Z Std = 13.74 µm

Z dev max = 59.48 µm

Z dev min = -61.92 µm



6.2.3 Reproducibility / pin tip center – XLD contour

XY Std = 2.89 µm

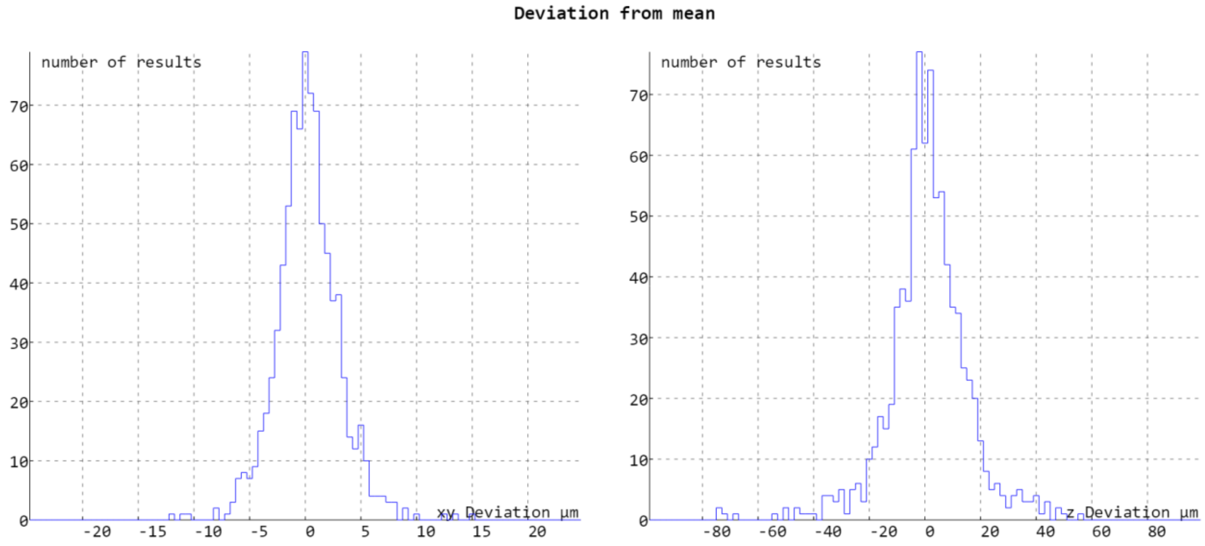
XY dev max = 14.61 µm

XY dev min = -12.32 µm

Z Std = 15.07 µm

Z dev max = 55.16 µm

Z dev min = -75.87 µm



6.2.4 Reproducibility / pin tip center – threshold

XY Std = 3.45 µm

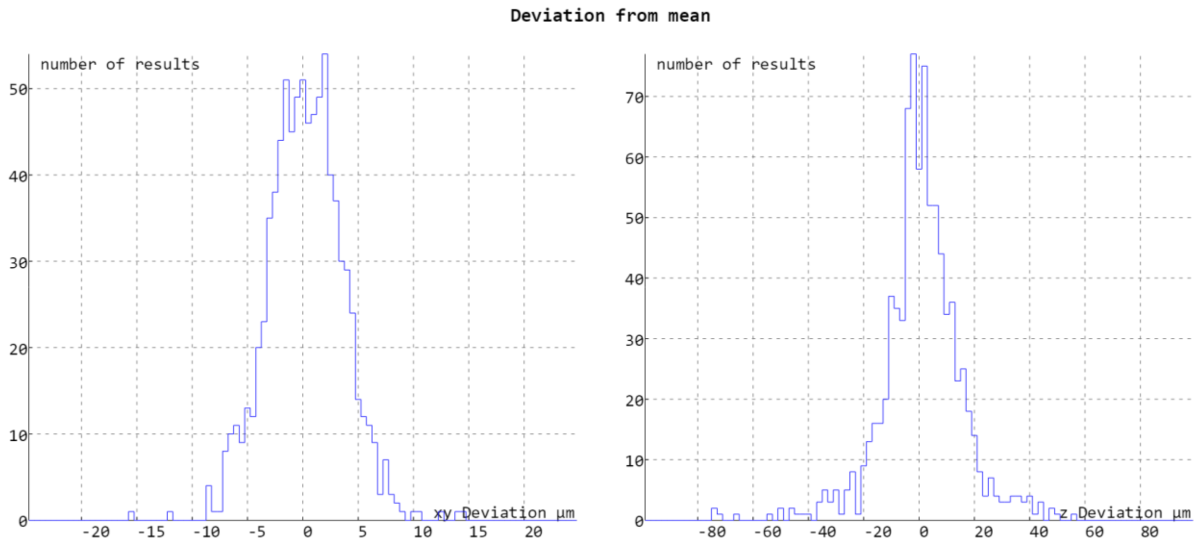
XY dev max = 14.25 µm

XY dev min = -15.56 µm

Z Std = 15.09 µm

Z dev max = 55.32 µm

Z dev min = -75.97 µm



6.3 Verification interpretation

The standard deviation of the z deviation is almost equal for every measurement row. This is a very plausible result. The accuracy of this value is limited by the precision of the block matching algorithm that finds corresponding parts in the images A and B. A displacement of the plug has no significant influence on the matching here. Also the precision of the pin center coordinates have no effect on the height measurement. The camera is specified with a height resolution of 10µm. A standard deviation of about 14µm is a plausible result in this case.

As expected, the standard deviation of the xy-deviation for the repeatability measurement is lower than for the reproducibility measurement. The movement of the plug causes small differences in the alignment of the plug that results in another appearance of the plug in the image. This indicates that a more accurate mounting of the connector will further increase the accuracy of the measurement.
For the pin center measurement, the XLD edge finder algorithm provides better results. A subpixel exact algorithm is working here in the background. This improves the performance compared to a simple threshold algorithm.

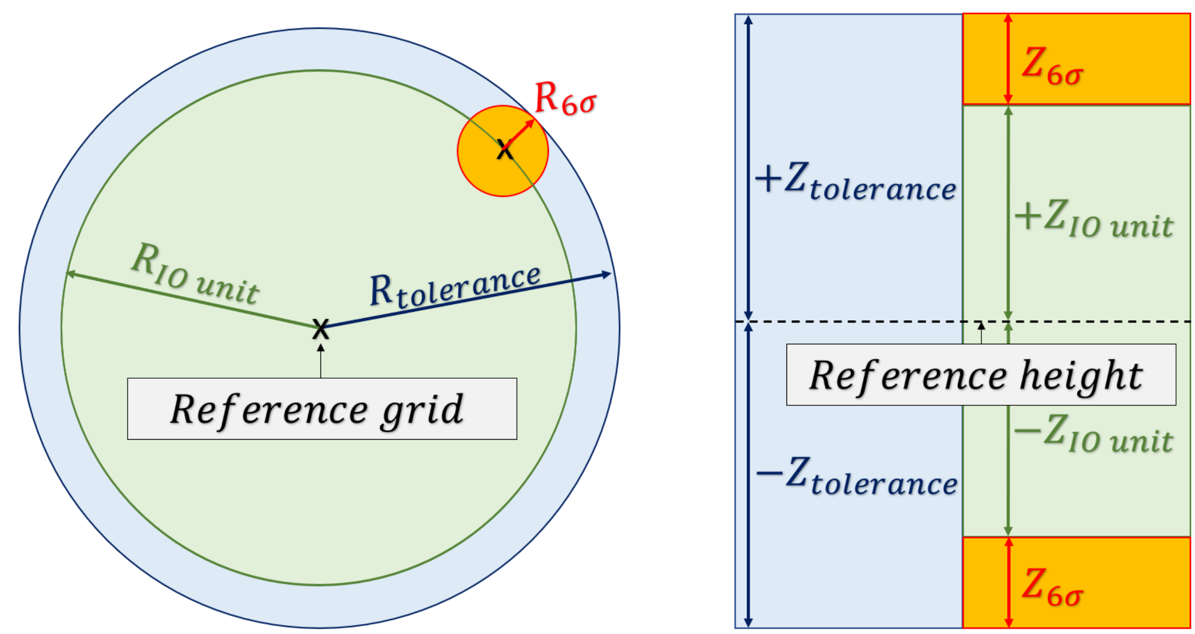
Related to the reproducibility measurement with the XLD contour algorithm are 99.99966% of the values in a range of $R_{6\sigma} = 17{,}3\mu m$ of the xy-deviation mean and $Z_{6\sigma} = \pm 90.42\mu m$ z-deviation mean. This is valid under the assumption that the measured values are normally distributed.
In the following an example project with the required tolerances $R_{tolerance} = 50\mu m$ and $Z_{tolerance} = 100\mu m$ is considered. The process capability index for this example is calculated below.

$$C_p = \frac{USL - LSL}{6\sigma}$$

$$C_p R = \frac{R_{tolerance}}{6\sigma} = 2{,}9$$

$$C_p Z = \frac{2 * Z_{tolerance}}{6\sigma} = 2{,}2$$

A $C_p \geq 2$ corresponds to the 6-sigma quality standard. The measurement process fulfills the requirement in this example.



7. Summary

We have shown, that Chromasens 3DPIXA cameras can be used in the field of connector pin inspection. The 3D position of every single tip can be measured at a high acquisition speed. With a 3DPIXA 30µm, a plug width of 20mm and a plug height of 60mm (mounting included) it's possible to measure 50 plugs per second. (5 plugs in a row, 10 rows per second)

The measured tolerances of the 3D position of the pin tips are suitable to fulfill the high-quality standards which are demanded by the automotive industry.

All image data and the applied image processing implemented exemplarily in Halcon can be found accompanying to this report.

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