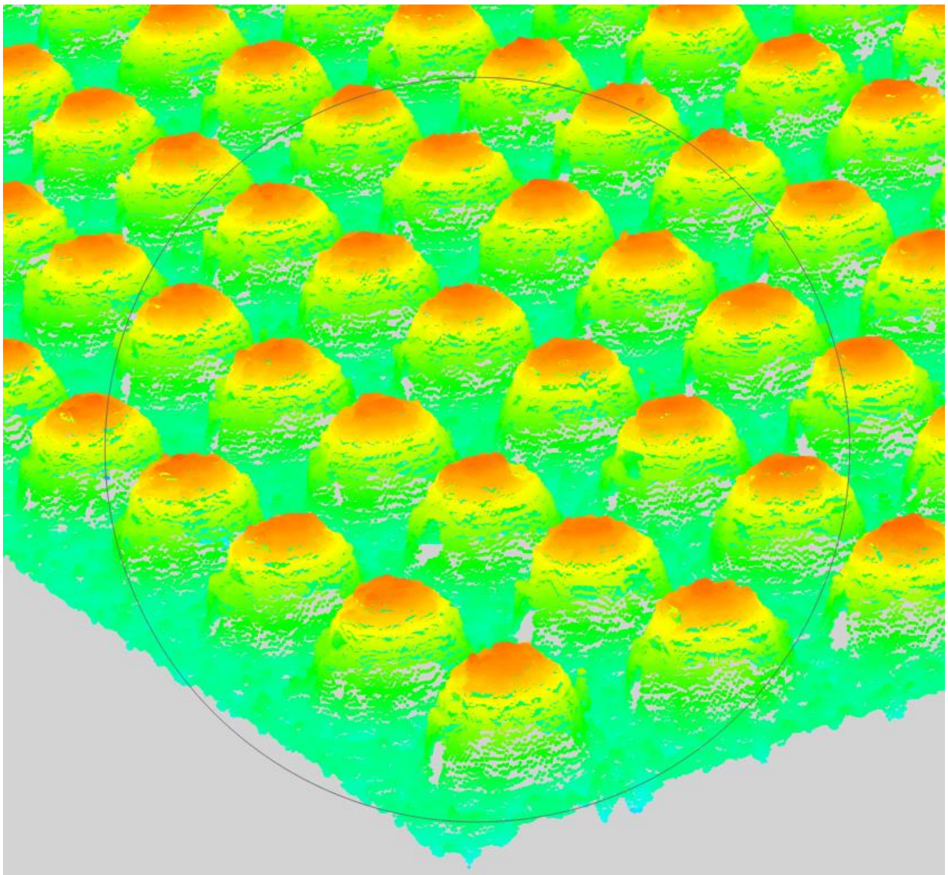
3DPIXA wave for BGA inspection

Application report



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Content

1. Application Outline

In the electronics and semiconductor industry soldering connections using BGAs (Ball Grid Arrays) are wide spread. Most prominent examples are the mounting of microprocessors. The big advantage of BGA packages is that the whole bottom surface of the package can be used instead of the bare perimeter. One BGA often consist of hundreds of single solder balls. To ensure the functionality of the electrical components, it is necessary that every single solder ball lead to a solid solder connection. The only way to ensure this is a one hundred percent inspection, where each solder ball must be measured three-dimensionally. Critical dimensions which need to be measured are for example the arrangement of the grid, the ball height or the ball coplanarity. Also, missing balls and defects of the substrate must be detected. With a one hundred percent control, it is possible to detect and sort out BGAs that do not meet the quality requirements. If defective BGAs are sorted out before the soldering process, significant costs can be saved.

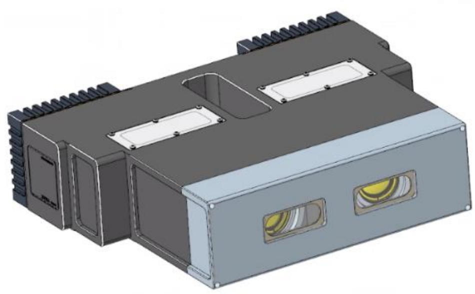
The complete measurement task is very demanding. A large number of balls must be measured for various quality criteria in a very short time. To ensure a very high throughput, allowing for a one hundred percent inline inspection, the system must be able to test multiple BGAs in parallel.

The combination of the high resolution 2D color image and high 3D measurement accuracy with an extremely high acquisition speed makes the Chromasens 3DPIXAwave the perfect measuring device for this challenging 3D vision application. The following report presents technical details and achieved results for the 3D BGA inspection tasks employing Chromasens 3DPIXA wave cameras.

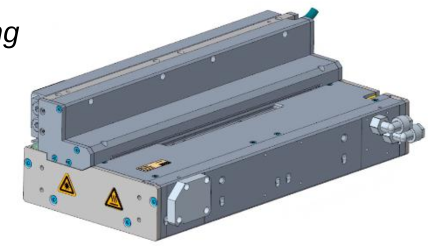
2. Scanning environment

Chromasens develops all key components for the measurement task. This includes hardware like the 3DPIXA linescan camera, illumination components like the Corona II Combined Illumination and a high-end illumination controller. Also, the software to parameterize the camera or calculate the 3D results are Chromasens products. This ensures a smooth start-up through compatible components and support from a single source.

2.1 Hardware environment



- **3DPIXA** **CP000600-D02-010-150**
  highspeed 3D linescan camera
  - Optical resolution: 10µm
  - Height range: 1.83mm
  - Field of view: 150mm
  - Max Speed: 184mm/s



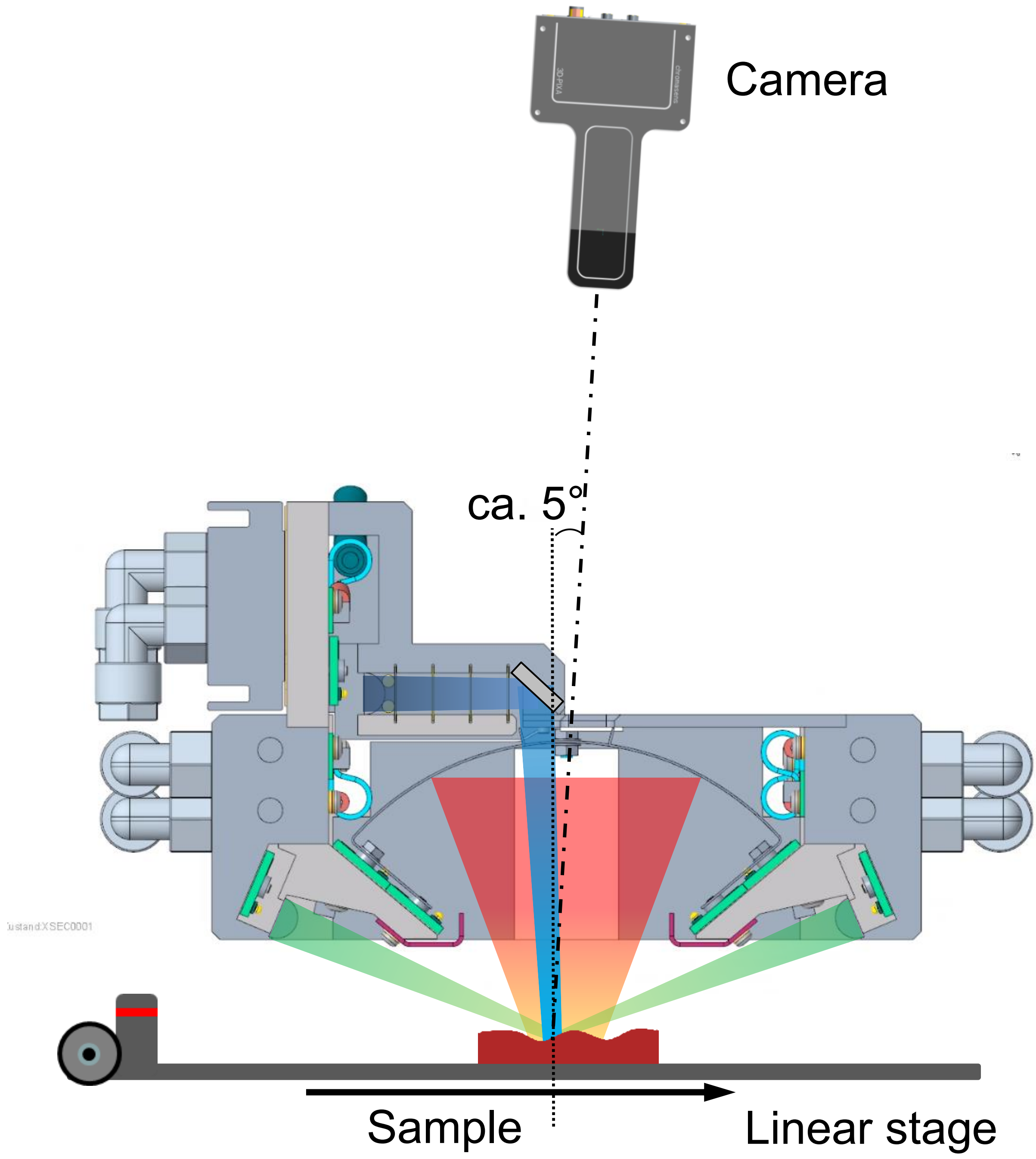
- **Corona II** **CP000606**
  Illumination system for three illumination types in one housing
  - Tube light (diffuse) - red channel
  - Darkfield - green channel
  - Brightfield - blue channel
  - Length: 340mm
  - Water cooled

- **XLC4** **CP000411**
  illumination controller
  - 4 current controlled output channels
  - 200 to 1800mA for each channel
  - Interface for synchronization with the camera as flash-image acquisition
  - Light module temperature monitoring
  - Control of cooling fan

If the demanded FOV is much smaller than 150mm the 3DPIXA compact series can be used. These cameras are available in multiple resolutions, are very easy to integrate and show an outstanding cost/performance ratio.[1]

[1] https://www.chromasens.de/en/products/line-scan-cameras-3d-inspection

The test setup is illustrated schematically below. The camera is aligned in a 5-degree angle to the surface of the BGAs. This ensures the functionality of the bright field component of the illumination. The following drawing illustrates the concept of the vision system.



The tube illumination (diffuse light) is used to illuminate the balls of the BGA over a large range of angles. The diffuse light illuminates the balls homogeneous from every direction. This ensures the best 3D data reconstruction of the ball surface from the stereoscopic image data.

The bright field illumination is used to illuminate the substrate of the BGA. The substrate appears bright and the surface is well textured. This ensures a good 3D reconstruction of the surface of the substrate.

With the darkfield component it is possible to detect defects, dust or other contaminations on the surface of the substrate.

Due the 3 different colors of the illumination, it is possible to acquire an image with a high density of information in which all quality characteristics can be checked.

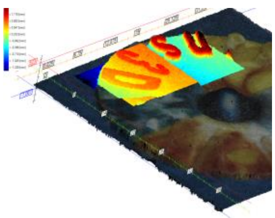
2.2 Software environment

Software Used

- 3D API Version 3.1
- Halcon Version 19.11 Progress

The Chromasens 3D API provides a wide range of functions to generate 3D data. The 3D API has a visualization called Chromasens 3D viewer. All functions of the 3D API are accessible here via the graphical user interface. It is possible to display different result types here. This makes the startup and the parameter tuning very convenient.
The different result types are shown in the image below.

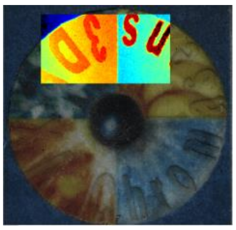
3D Point cloud



Graphic 3D visualisation of the calculated surface points

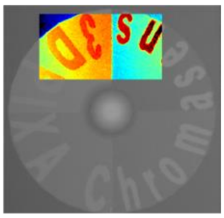
Central View: correction of the resolution changing over the height.

Rectified image



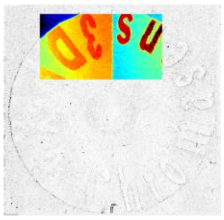
Distortion corrected image for 2D measurements

Height Map



The height map shows the surface height as a grey value image.

Confidence Map



The confidence map shows the degree of conformity of the matching algorithm.

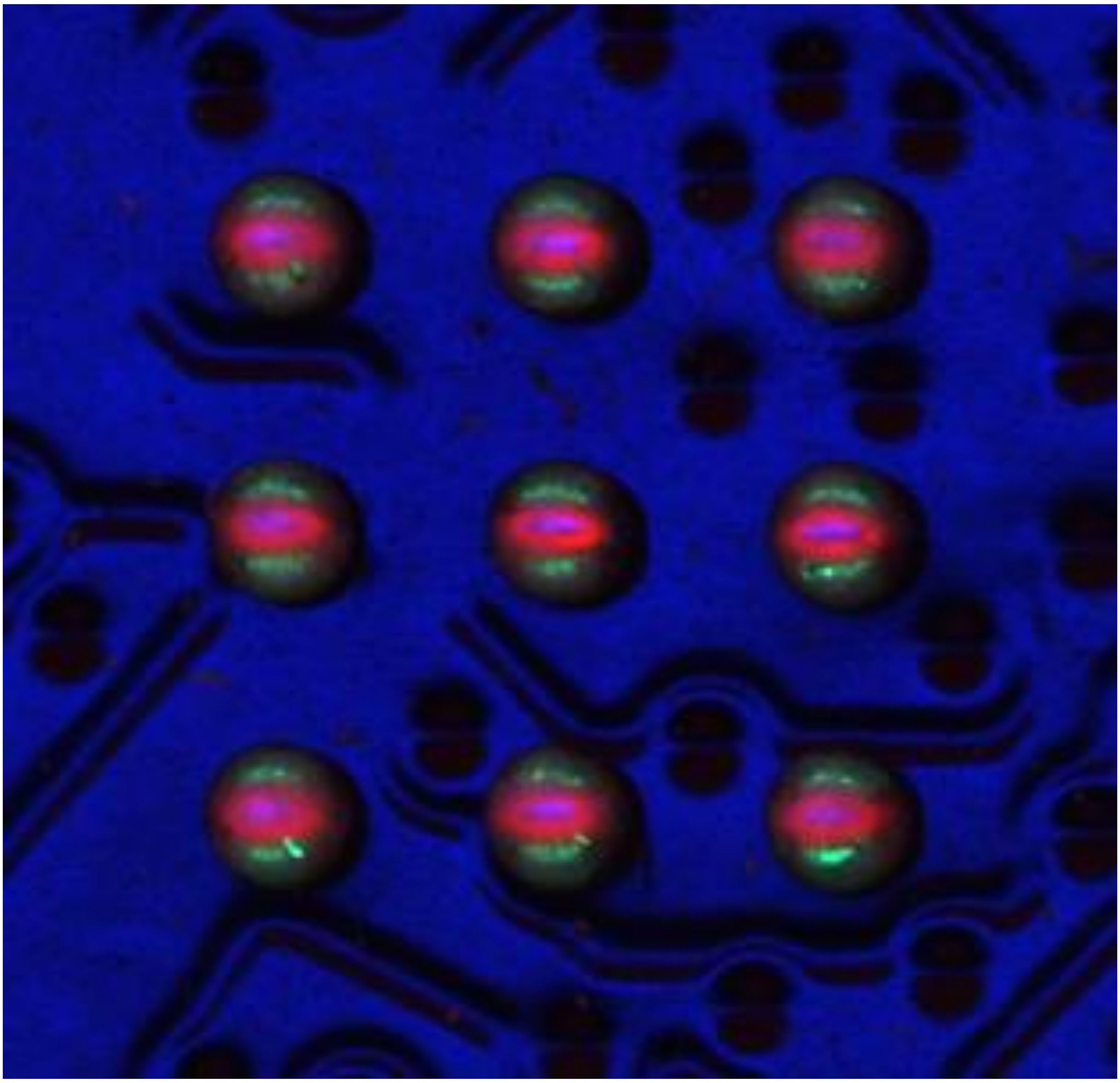
The 3D API is a C++ 3D processing library, a C# wrapper is also available. In addition, a Halcon and LabView user extension is implemented. The image processing is performed with Halcon for this example; meaning that all functions of the API can be easily and conveniently used in the Halcon environment.

3. Acquiring images

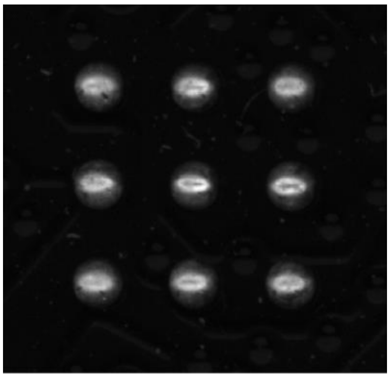
In order to achieve the best results, there are some rules for the image acquisition.

A good image for 3D calculation must be properly illuminated. This means in detail that overexposed parts of the image must be absolutely avoided. The darker parts of the image must be bright enough to contain image information that exceeds the noise level of the camera. In many cases this causes problems because there are bright and dark regions within the same image – a common property of BGAs. The highly reflective balls appear very bright with a conventional diffuse illumination, the substrate reflects less light, and the texture of the surface is not rich in contrast.
With the combined illumination it is possible to avoid these issues. It is advisable to select the illumination situation in the way that the brightest points are represented with approximately 220 to 240 DN (Digital Number @ 8bit) in the image. It is possible to set up the brightness of the balls with the red diffuse illumination, and the brightness of the substrate can be controlled with the blue brightfield illumination. A possible overexposure of the balls in the blue channel can be neglected because this channel is only used to calculate the height information of the substrate. The height information of the balls is calculated with the red channel of the image.

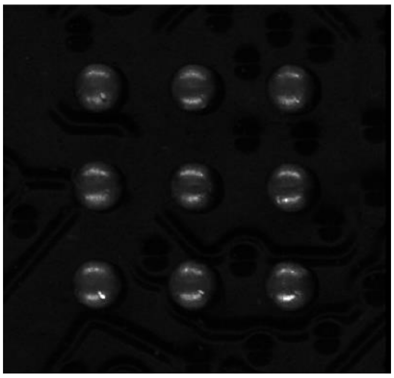
The following image shows an example for a BGA acquired with the 10µm dual 3DPIXA camera (CP000600-D02-010-150) and the combined illumination (CP000606).



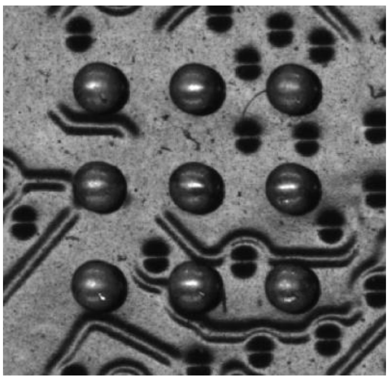
Red
tubelight



Green
darkfield



Blue
brightfield



A further aspect of the image acquisition is the noise level of the image. A noisy image reduces the quality of the 3D reconstruction especially in darker image regions, parts with a weak texture and parts that are far away from the working distance.

The most important instrument to reduce the image signal noise are the gain settings of the camera. The best possible situation are very low gains. For a very fast acquisition the illumination system can limit the vision system performance. A high-power light source allows low gains and a high acquisition speed.

Additional best practices for ideal image quality are:

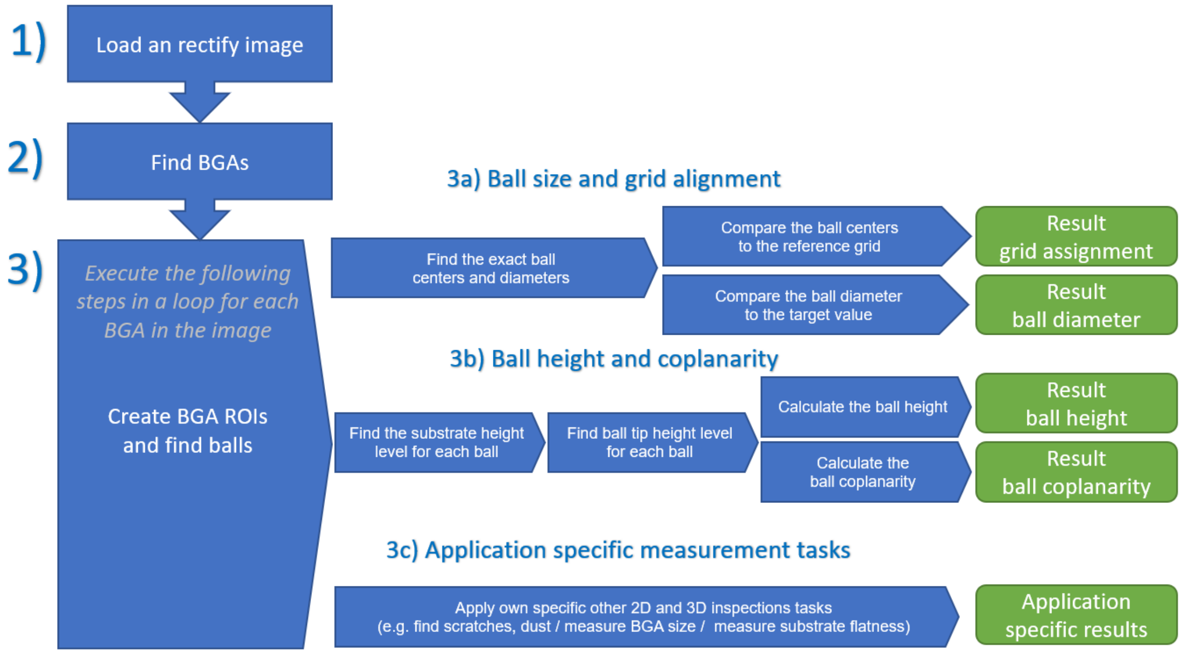
- The available integration time should always be used to the maximum.
- The linear gains should be kept low. Use the CDS gains and the “high sensitivity” mode to reduce the linear gains as much as possible. (refer to the camera manual for further information)

Another issue that can occur is image warping caused by heat-induced turbulences of the air in the optical path. This phenomenon also affects the 3D reconstruction in a negative way. More information is available in a published whitepaper on this topic[2].To avoid this problem a fan between the surface and the illumination can be used to generate a continuous air flow.

[2] https://www.chromasens.de/en/blog/image-warping-caused-heat-induced-turbulence

4. Image processing

The following block diagram shows a possible procedure for evaluating BGAs.

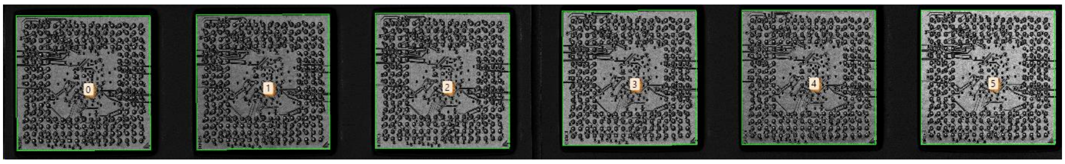


The image processing is performed with Halcon[3]. The sample code can be provided upon request to allow for fast start up and integration; however, other image processing libraries are also suitable to handle the data. This report is intended to show the general image processing procedure.

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

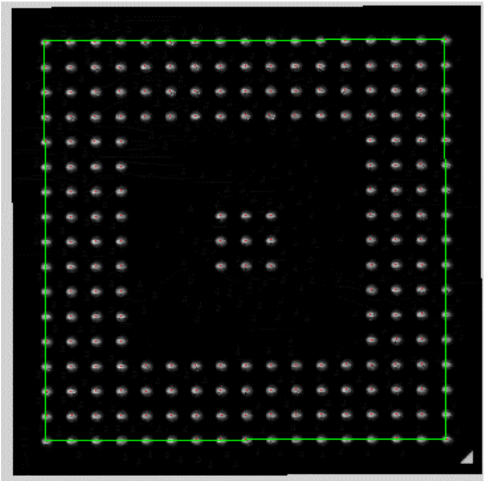
1) **Load and rectify image**
   After loading the image in Halcon, the CS-API is used to rectify the images and generate the height data. Distortion and other image errors are corrected in the rectified image.

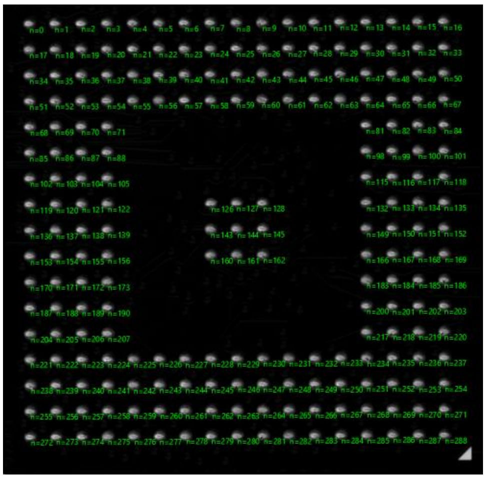
2) **Find the BGAs in the image**
   Due the very large FOV (150mm) of the camera, the system can scan multiple BGAs in parallel. The position and alignment must be determined, for each BGA.



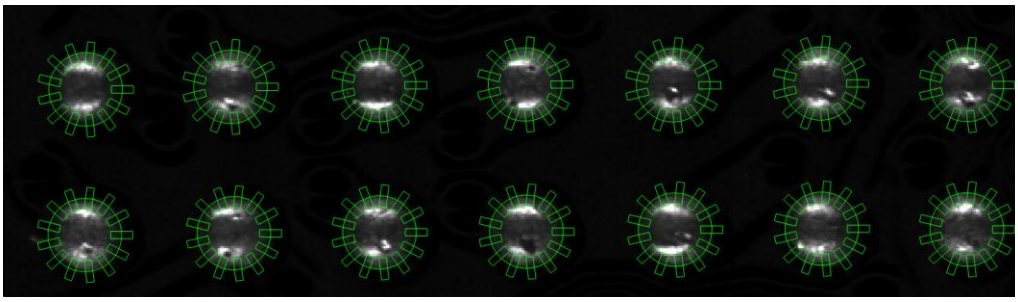
[3] https://www.mvtec.com/

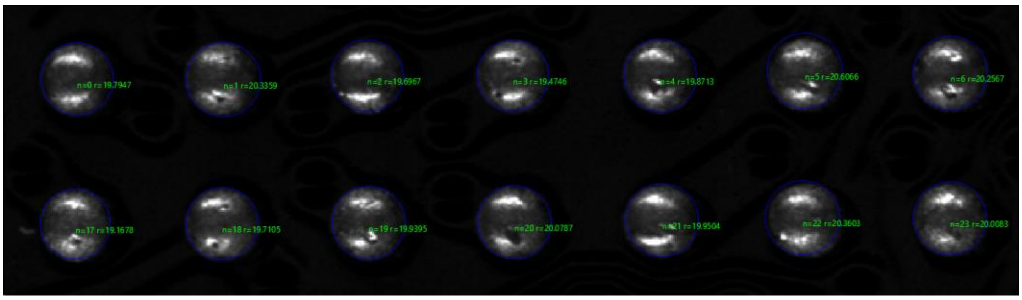
3) **Create ROI and detect the balls**
The following steps are done for each BGA found, in a loop. The balls can be found with a simple threshold operation. Halcon provides a function that creates the smallest enclosing rectangle around points. In this case these points are the ball centers. This function is very useful in this case to very precisely determine the alignment of the BGA. If the balls are arranged in a grid, the balls can be easily sorted in a defined. Also in this case, spaces in the grid are numbered, which is useful when the script is used for different types of BGAs.



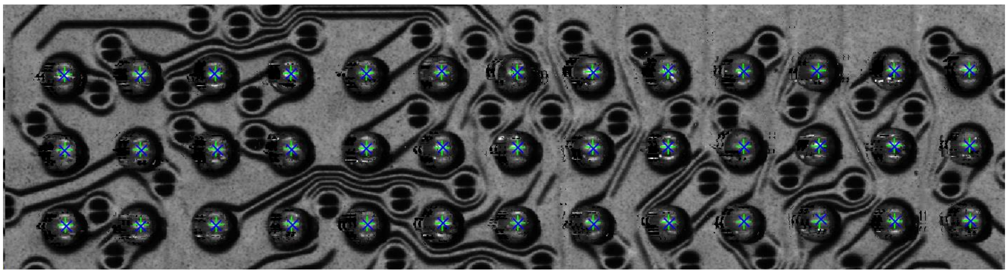


a. **Ball size and grid alignment**
<u>Find the exact ball center and diameter</u>
A Halcon 2D measurement tool is used to improve the accuracy of the ball center coordinates and calculate the ball diameter. This tool can very precisely measure objects that represent a geometric shape. In this case the ball represents a circle. For this measurement, the dark field image is used. The transition from the substrate to the ball appears with a high contrast in this image.





Compare the ball center coordinates with a reference grid
An important quality criteria of BGAs is the arrangement of the grid. To check this, the Chromasens 3D API can calculate perspective corrected coordinates. This function compensates the change of resolution of the optical system with the distance to the object due to the conically widening beam path (endocentric optics). A reference grid can be defined and compared with the measured grid utilizing 2D fitting (least square method).
For visualization reasons the image is perspective corrected. This can cause some image artifacts near large height steps.

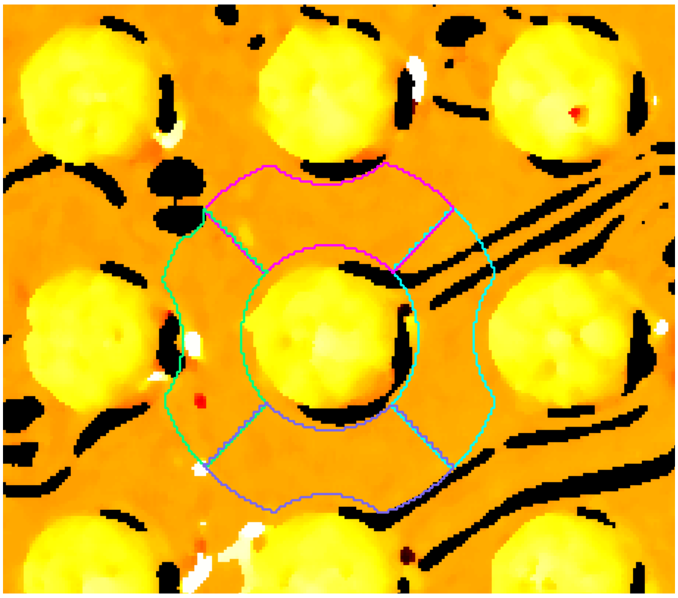


b. **Ball height and coplanarity**

Find the substrate height level for each ball
The substrate level is calculated here with the blue bright field image. If SGM is used to calculate the 3D data, large values for the penalty parameters p1 and p2 can be selected. This penalizes big height steps which are not expected here. For block matching, the window size can be selected to a large value. The SGM parameters in this case are

$$p1 = 15$$
$$p2 = 70$$

This helps to reduce noise and outliers even for very demanding surfaces.
In the most cases the BGA is angled in the mounting or the substrate is curved. For this reason, it is useful to calculate the substrate level for every ball separately with 4 reference points. The height level of these reference points is the mean value of a suitable region. The following image shows the regions for the calculation of the reference points. To reduce outliers a strong median filter can be used here if necessary.

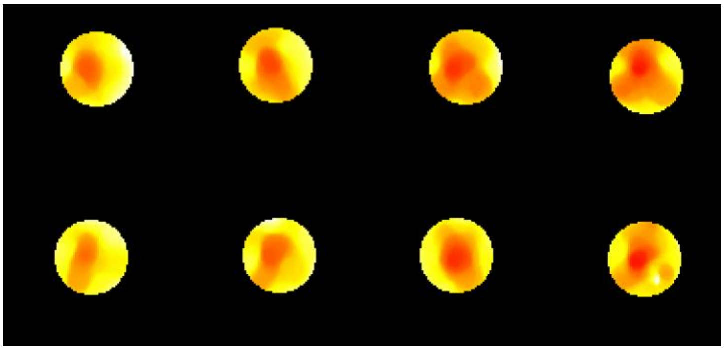


Find the ball peak height level for each ball

A gray map histogram analysis is used to find the ball peak. Therefore, a histogram of the height map is generated for a small circular area around the ball center for each ball.

In order to avoid outliers being recognized as ball peaks, values in the histogram that deviate too much from the expected distribution on a height map of a spherical shape are neglected.

Filters that are too strong (e.g. median filter) can lead to a low pass filter effect which systematically falsifies the measurement result: ball height too small.



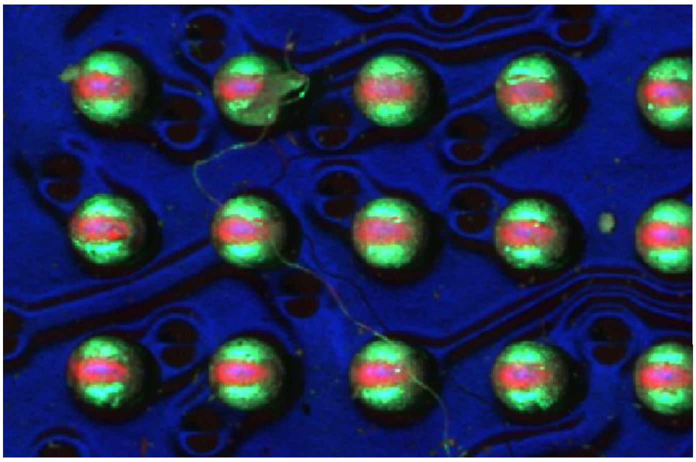
Calculate the ball height and coplanarity.

With the height of the substrate and the height of the ball it is possible to calculate the following properties:

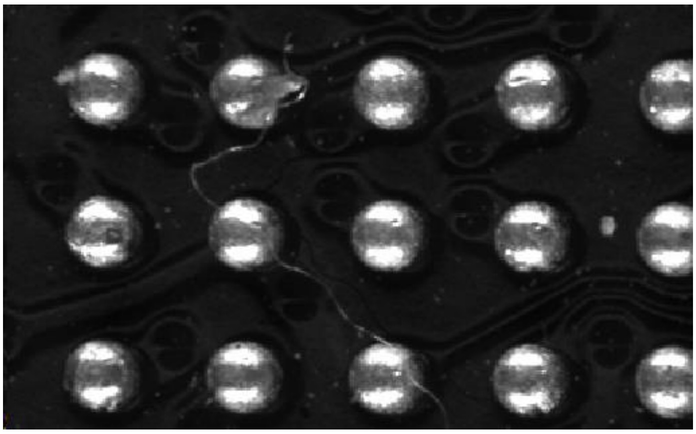
- The ball height (Ball top level – Substrate level)
- The ball coplanarity in reference to the ball height
- The ball coplanarity in reference to the absolute ball height level

c. Application specific measurement tasks

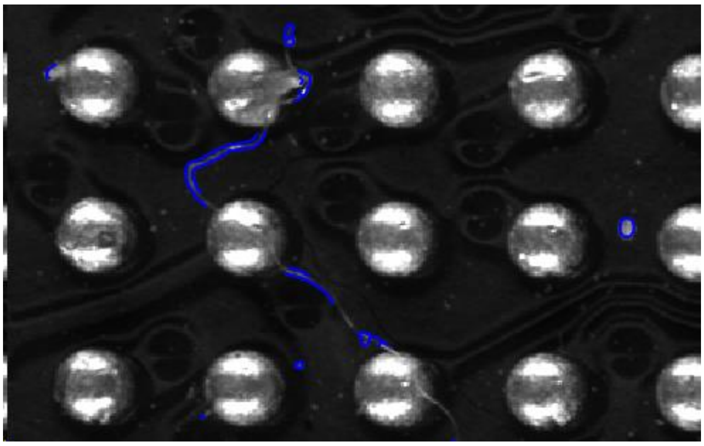
Various additional quality criteria for BGAs can result depending on the requirements. A typical further quality criteria is the recognition of dust or other contaminations. The dark field illumination is very useful for this inspection task. Contaminations appear very bright in the image and can be found easily. The following example shows a part of the image that is contaminated with dust and a very thin fibre.



RGB Image



Green darkfield channel

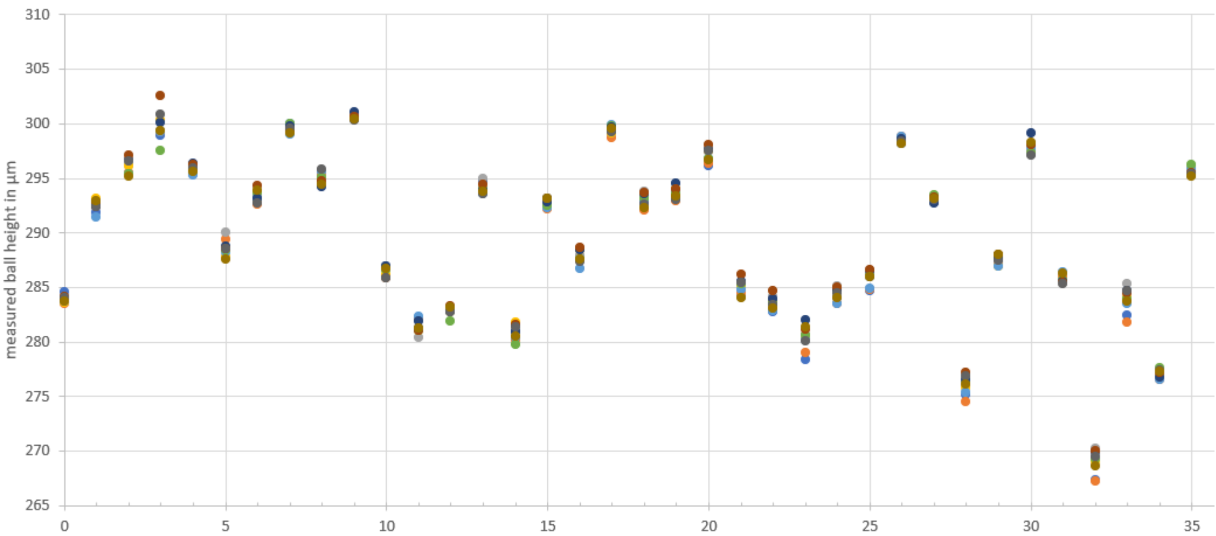


Green darkfield channel with edge detection filter function

5. Verify the measurement

The goal of the verification is to calculate the scattering of the results of the measurement. The smaller the scattering, the better the measurement system works.

The most important measurement value is the ball height in this case. With this value it is possible to check various properties of the BGA. Therefore, the accuracy of this value should be verified.
The following diagram shows exemplary the ball height of the first 35 balls. The height is measured 10 times. The deviations that can be seen here will be systematically evaluated in the following part.



5.1 Verification approach

The evaluation of the measurement is separated in the reproducibility and repeatability. For both measurements, a stack of 10 images of the same BGAs are acquired. To guarantee for the best possible measurement conditions, the system is powered up 2 hours before the data acquisition starts.

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

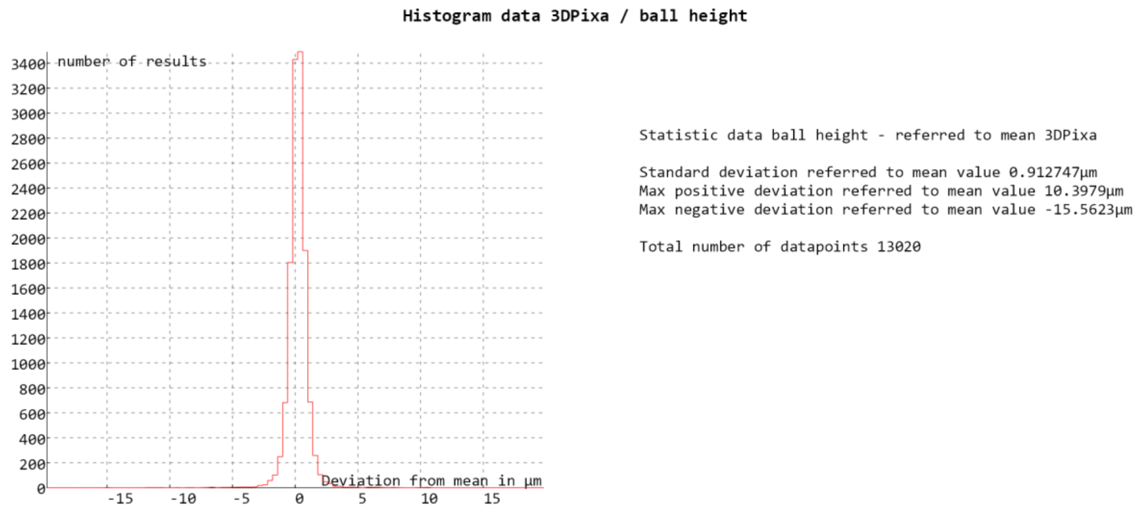
For the reproducibility measurement the BGAs are replaced by hand between every acquisition. The position and alignment changes in every image.

With 6 BGAs in one image and 217 balls per BGA one image contains 1302 balls. In this approach 10 images are used to calculate the standard deviation of the measurement system. Consequently, there are 10 height values for each of the 1302 balls. From these 13020 measurements (1302 balls *10 measurements), 1302 variances are calculated (1 for each ball). From the mean value of these variances the standard deviation of the measurement is calculated by root extraction.

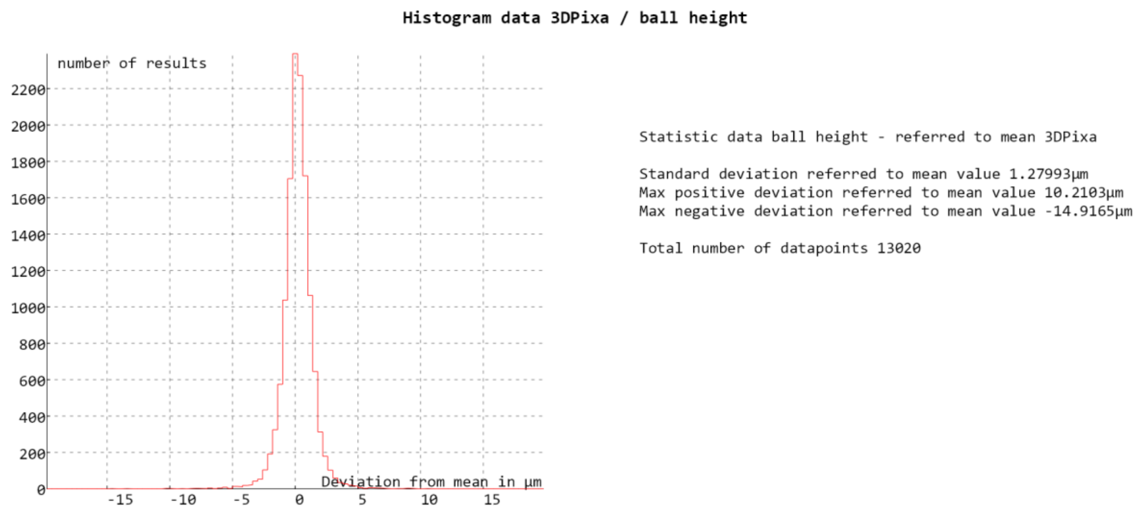
5.2 Verification result

In the following section the verification results are shown and compared. Note that the system is evaluated as a unit. This includes image acquisition processing. The result therefore has a physical component (image acquisition) and an image processing component. With another image processing algorithm, the results will be different.

5.2.1 Repeatability 10um dual



5.2.2 Reproducibility 10 um dual



5.3 Result interpretation

Related to the reproducibility measurement are 99.99966% of the values in a range of $H_{6\sigma} = 7{,}68\mu m$. This is valid under the assumption that the measured values are normally distributed. In the following example project a ball height tolerance ($H_{tolerance} = 25\mu m$) will be assumed.

$$C_p = \frac{USL - LSL}{6\sigma}$$
$$C_p = \frac{H_{tolerance}}{6\sigma} = 3{,}2$$
$$P/T_{ratio} = \frac{1}{C_p} = 0{,}31$$

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

6. Summary

This report shows the capability of a 3DPIXA inspection system for BGA quality assurance using state-of-the-art machine vision approaches and image capture technology. Multiple measurement tasks can be carried out in a very short time with high precision.
The unique combination of high resolution RGB color images and 3D measurements allow for a very flexible and comprehensive measurement with one measurement tool.

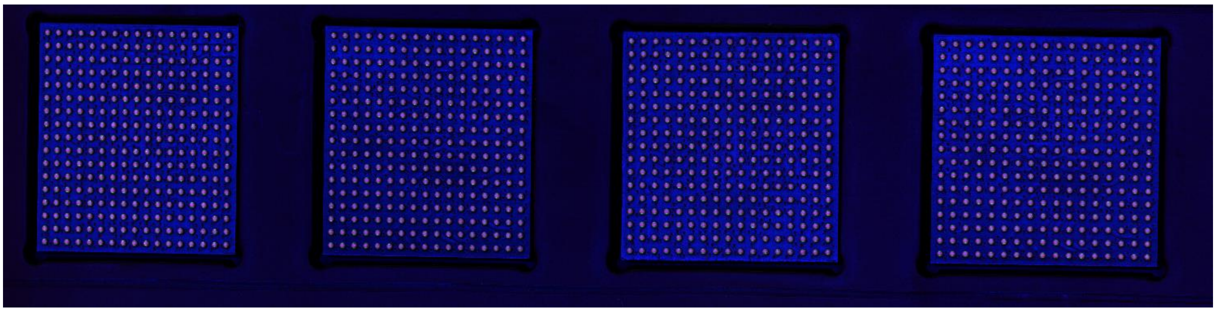
With the 3DPIXA 10µm dual and a BGA size of 18mm x 18mm (mounting included) it is possible to measure 80 BGAs per second. (8 BGAs in a row, 10 rows per second). The BGA type measured in this report has 217 solder balls. This means that 17360 solder balls per second can be measured in a rigorous 100% inspection scenario with one 3DPIXA wave camera.

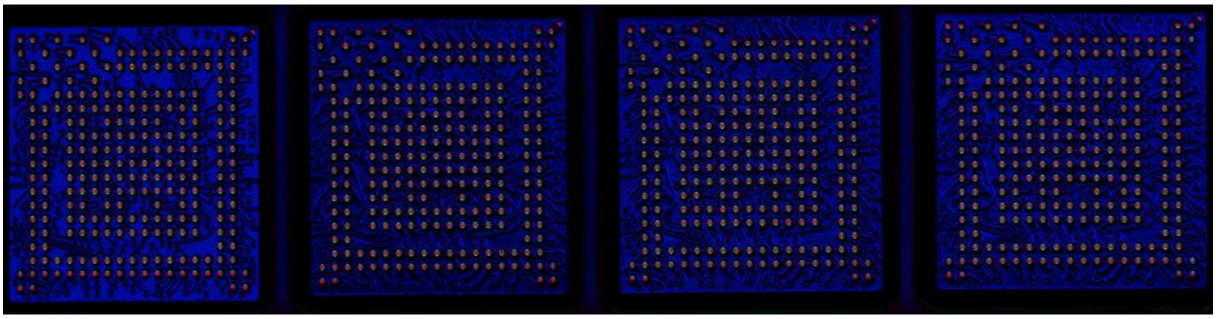
In the report it is verified that the quality of the 3DPIXA based vision system fulfills the high-quality standards which are demanded in the semiconductor and electronics industry. The Chromasens components in this report are an example to solve a typical BGA measurement task. For other requirements, a wide range of 3D cameras and line light sources are available from Chromasens. Customizations and fully integrated visions systems can be provided on demand.

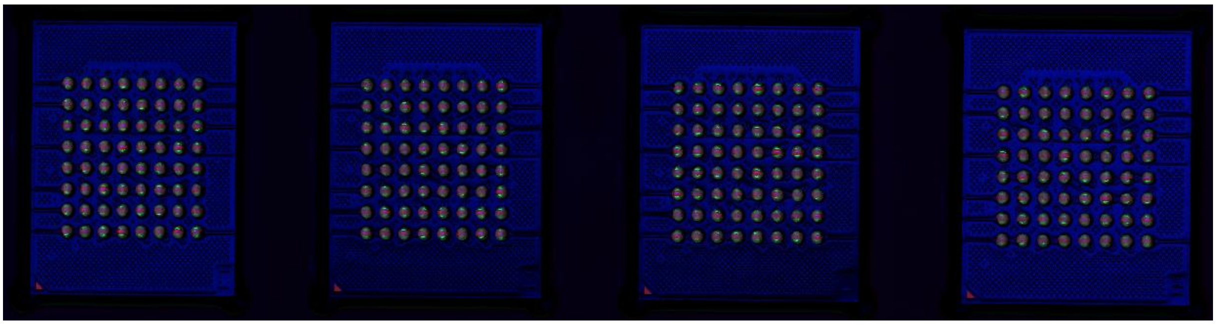
3D Line scan systems:
https://www.chromasens.de/en/products/line-scan-cameras-3d-inspection

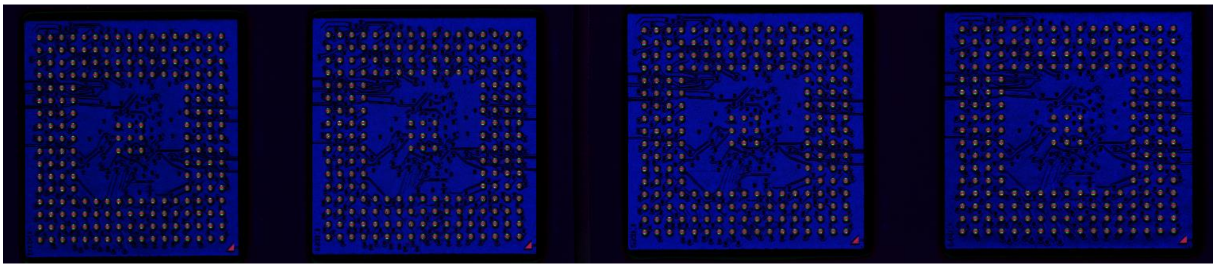
Chromasens line light sources:
https://www.chromasens.de/en/product/corona-ii-led-line-scan-light

Finally, we present some images from different types of BGAs illustrated.









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