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Imaging for Professionals

3DPIXA: options and challenges with wirebond inspection

Whitepaper

Version	Author(s)	Date
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Executive Summary:

Wirebond inspection using 3DPIXA technology poses challenges under certain circumstances. We have summarized recommendations for application design and vision component setup. Further, the most critical challenges in the application are outlined and illustrated, and potential problem solving strategies discussed.

Content:

1. Introduction

Inspecting wire bonding processes inline is currently one of the most challenging tasks in machine vision. Traditional inspection is performed on 2D images, color or grayscale, and consists for instance of:

- Wire tracing
- Bent and broken wire detection
- Wire solder spot / wedge analysis
- Wire attendance check

2D inspection is insufficient for some tasks and 3D information is required. Chromasens 3DPIXA provides such information in form of a "height" (disparity) image, in addition to the conventional color or grayscale image.

However, 3DPIXA is a stereo imaging based technology, and the stereo imaging principle poses some restrictions with respect to generating useful height information in wirebond images.

In what follows, an optimized image acquisition setup, as well as the main challenges in wirebond inspection is discussed.

1.1 Image acquisition setup

1.1.1 Camera system

Wires for bonding can range from few microns to few hundreds of microns in diameter, so selecting the optical resolution of a 3DPIXA highly depends on the requirements and cannot be generalized. Further, height resolution, height range and FOV have to be taken into account when selecting a suitable camera. Table 1 lists typical choices:

	CP000520-D01-015-0105	CP000470-C01-015-0040	CP000520-D02-005-035	CP000520-D02-002-016
Camera type	Dual	Compact	Dual-HR	Dual-HR
Optical resolution (µm/px)	15	15	5	2.5
Height resolution* (µm)	3	4	0.55	0.35
Height range* (mm)	3.5	2.6	0.5	0.2
Field of view (mm)	105	40	35	16
Typical min wire size (mm)	0.075	0.075	0.025	0.012

*) height range and height resolution depend on object surface and might be higher

Table 1: Typical choices of 3DPIXA for wirebond inspection

1.1.2 Light source

The most suitable light source for wirebond inspection is a tubelight of type Corona II (**CP000200-XXXT-XX-XXX**), as using that will provide a homogeneous spatial illumination with great temporal and spectral stability. Using directional light sources (such as Corona II dark field) is not advisable, as strong shadows from the wires result from that.

1.1.3 Schematic setup

Camera and light source are generally to be installed with distances from the scan surface in accordance with the values specified in corresponding technical drawings. The schematic setup is illustrated in Figure 1.

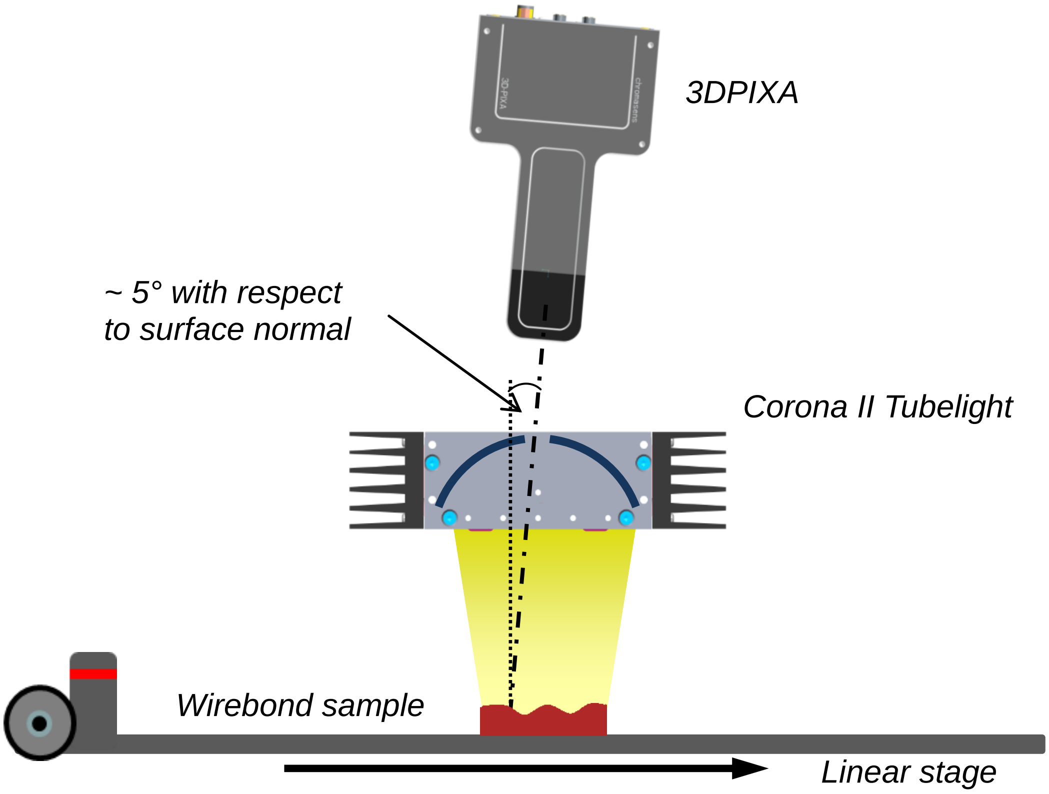
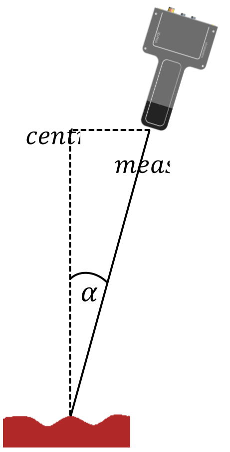


Figure 1: Schematic illustration of imaging system components

However, it is advisable to have the 3DPIXA mounted at an angle of approximately 5° tilted with respect to the surface normal (scan line). By that, the camera observes the object at a location where the scene illumination is stronger than as if the camera is mounted at 0°.

Please note: tilting the camera results in perspective scanned image data. If heights are to be measured from central perspective, the measurements are to be corrected by multiplying the values with the cosine of the tilt angle. This correction is illustrated in Figure 2.



$$central\ view\ height = \cos(\alpha) * measured\ height$$

Figure 2: Correcting camera tilt angle in height measurements.

2. Challenges

2.1 Horizontal wires

2.1.1 Problem statement

Stereo imaging using Chromasens linescan cameras makes use of a correlation based block-matching algorithm to estimate pixel-wise image correspondence, and from that image disparity. The correspondence search among left and right image of a stereo pair is performed in horizontal direction (along the sensor line).

For objects with horizontal structure that are void of texture, correspondence search can fail or perform low, as the image content of the block-matching is identical for multiple blocks in horizontal direction.

Bonding wires are an example of such structures. The wire's appearances are homogeneous along the wire, and they might occur in horizontal direction in the scanned image. An illustration of the problem is shown in Figure 3. From the disparity image, we see valid disparity values (homogeneous gray) for non-horizontal wires, and potentially wrong or not correlated values (inhomogeneous gray and black regions) for horizontal wires.

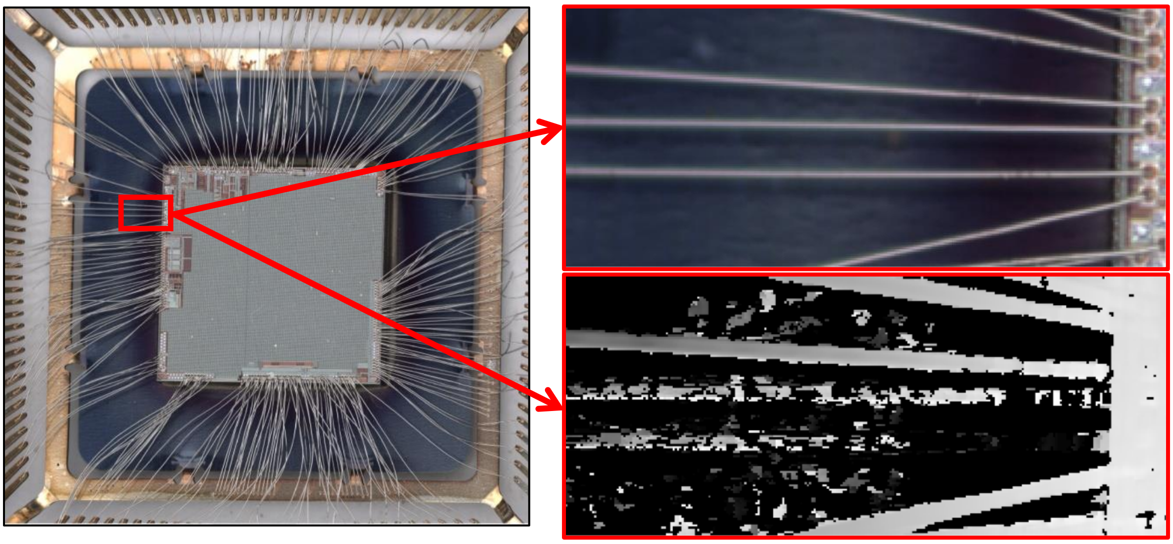


Figure 3: Wire-bond sample image (left); rectified image cropped ROI (upper right); disparity image cropped ROI (lower right)

2.1.2 Problem solving strategy

There exist potential solutions to this problem:

- If possible, rotate the scan object in the image plane such that no wires appear horizontally
- If possible, rotate the camera such that the scanline is not perpendicular to the scan direction anymore. See chapter 2.1.3.
- Use a pattern projector to create unique image texture on the wires [1]

The problem cannot be solved in software or by means of more sophisticated algorithms, as the bottleneck is missing information (image texture) in the raw image data.

[1] Chromasens does currently not have an adequate pattern projector for this application. Please contact us for discussion the possibility of developing custom hardware.

2.1.3 Remarks on camera rotation problem solving strategy

As mentioned before, the horizontal wire problem can be solved for some applications by rotating the camera with respect to the scan direction. The rotation angle has to be adjusted such that there exists no wire being parallel with the sensor line (eg. no horizontal wire in the image data). The setup is illustrated in the following figure:

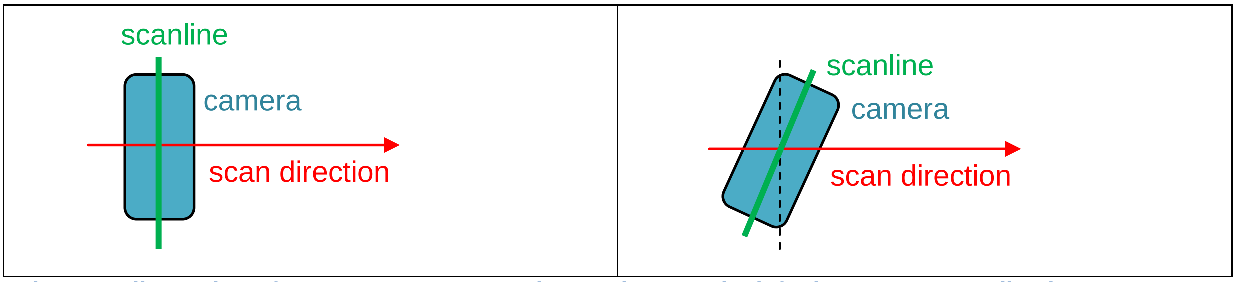


Figure 4: Illustration of camera system setup in top view. On the left, the camera scan line is perpendicular to the scan direction (*no rotation*). On the right, the camera scan line is rotated with respect to the scan direction.

From the following example, we can see the benefit of camera rotation in terms of reducing image regions with missing height information.

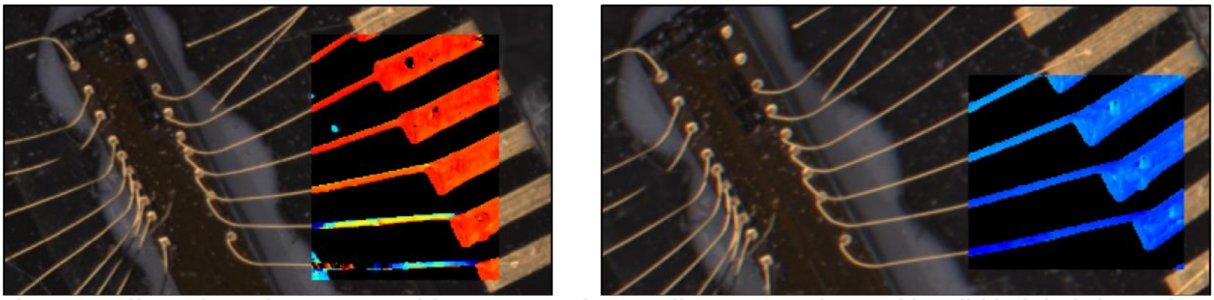


Figure 5: Effect of rotating camera with respect to the scanline. No rotation and invalid height information in horizontal wires (left image), rotation by ~ 10° (right image)

Note:

- A consequence of this rotation in case of line-scan cameras is that the image content is sheared (see Figure 6). Whenever geometrical measurements are to be performed in the 2D scan image, this might be a severe limitation. The image shear can be corrected for with a geometrical calibration and subsequent image post processing. However, this feature is not included in the 3DPIXA API as it is very application specific.
- For small angles of rotation, there is no influence on the image quality of the RGB image. With increasing angle, there exists an increasing shift of R-, G- and B-pixels in sensor direction, resulting in an optical low-pass filtering of the color image. However, if single channel 3D computation is used, there is no influence by the rotation.

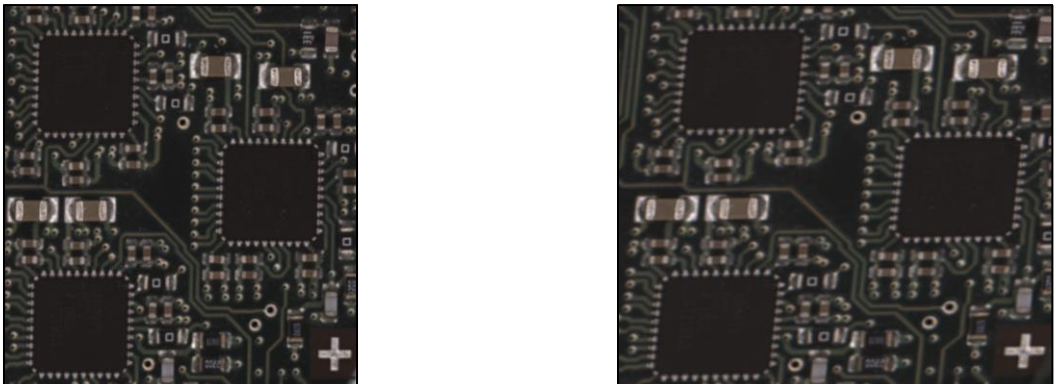


Figure 6: Sample scan image from un-rotated camera (left) and rotated camera (right). Note that these images have been rotated for illustration purpose in a post processing step to show the shearing effect.

2.2 Spacing of parallel vertical wires

2.2.1 Problem statement

The height range of the objects in the scan scene determines typically the minimum distance that parallel vertical wires can have in order for 3D calculation to work.

To understand this relation, we again have to recall how correlation based block-matching works. In Figure 7, left and right image of a stereo pair are shown. The red marked region in the left camera image is a reference block of a given window size. Using block-matching, its corresponding block is searched in the right camera image, within a predefined disparity search range (indicated in yellow). Take the case of the middle image in Figure 7. The disparity search range is selected rather small. By that, there is only one wire included (the one that matches the reference block). On the other hand, the right image in Figure 7 illustrates a case where the disparity search range covers multiple wires. Block-matching might fail due to ambiguous correspondence.

Limiting the disparity search range to ensure unique matching is not always possible, as this parameter determines the height range of the 3D measurement. It is typically selected according to the minimal and maximal object height in the region of interest for the inspection task, and selected globally for the whole image.

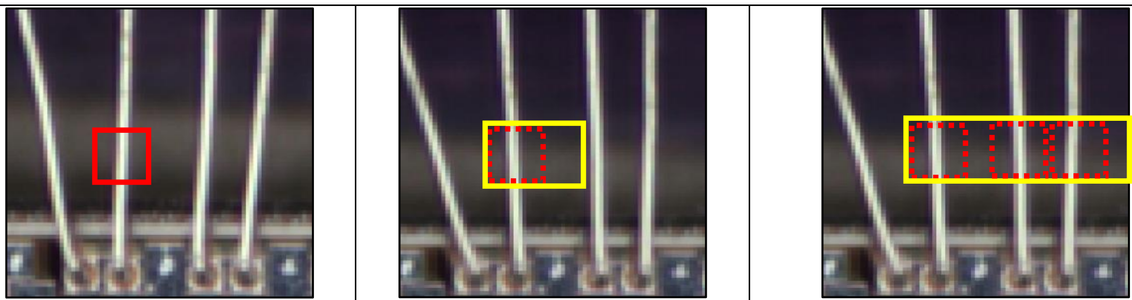


Figure 7: Relation of search range and potential ambiguous block-matching

2.2.2 Problem solving strategy

In applications where limiting the disparity search range is not possible, other approaches can be considered.

Segmenting and labelling wires:

2D image processing algorithms can be utilized to segment individual wires in right and left image of a stereo pair, followed by labelling corresponding wires. The labelling task is simple in most applications, as the image location of start and end of the wires (solder spots) are typically known.

Once this preprocessing is done, artificial image pairs, containing only wires for which unique matching is possible within the disparity search range, can be created. Using 3DAPI, corresponding disparity images can be computed and merged to a single height map.

In Figure 8, an illustration of the result of this approach as compared to conventional computation is given.

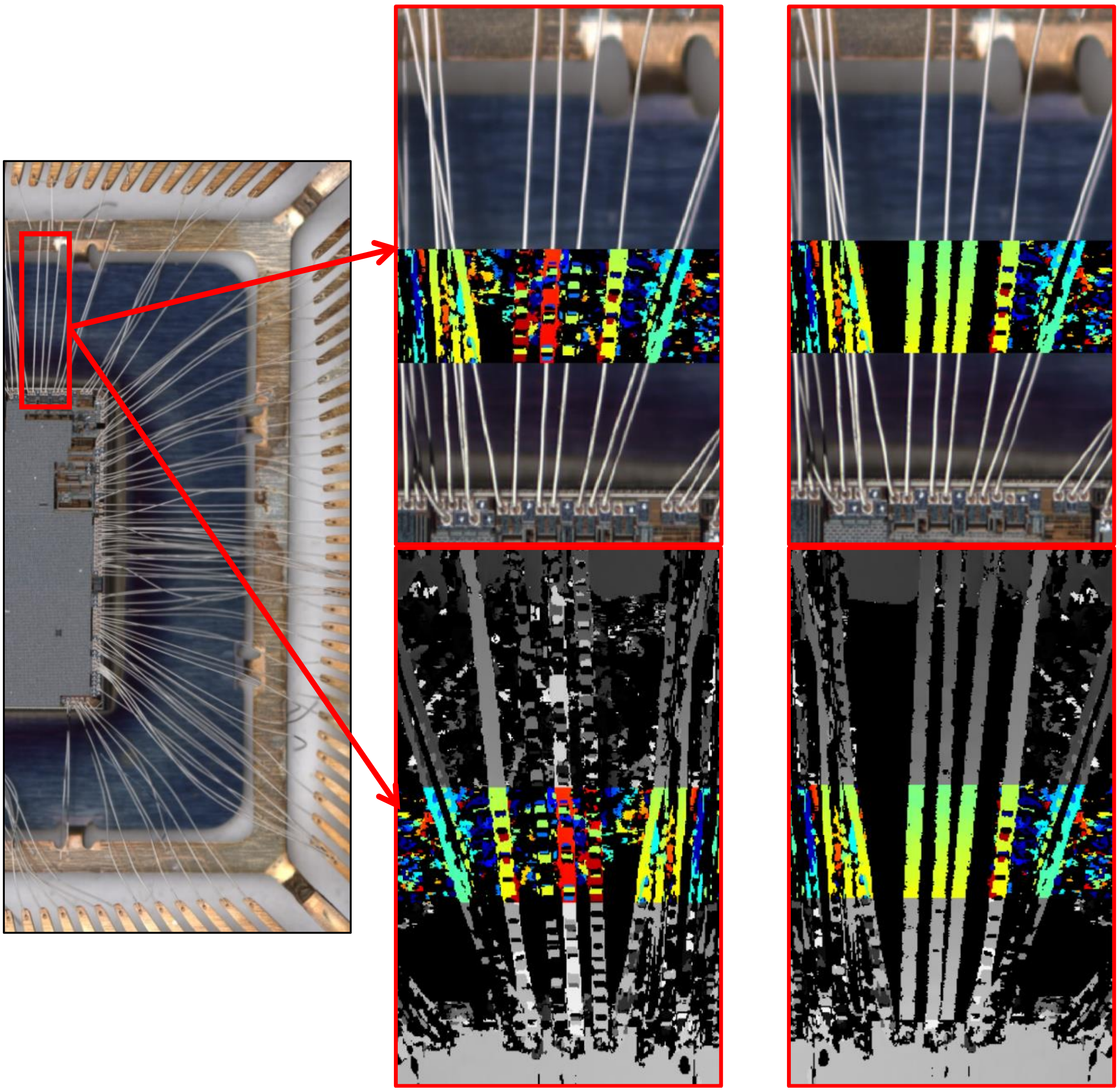


Figure 8: Comparison of results for conventional 3D computation (middle column) as compared to the *segmentation-labelling-merging* approach (right column).

Obviously, the computational demand of this approach grows with the number of image pairs with individual wires that are to be processed. Using distributed computing with multiple 3DAPI instances in parallel and at least one GPU per instance is a way to speed up.

Extracting feature points from the wires:

3DAPI has the functionality to compute 3D coordinates from corresponding image points of a stereo image pair. The function is called *rawImageCoordinatesTo3D* a detailed description is given in the *CS-3D-Api-Manual*. Based on that, the vertical wire problem can also be solved by using image processing to extract corresponding points on the wires of right and left stereo image. The resulting discrete 3D coordinates can then be merged to a global representation of the wires in a 3D image. By that way the image correlation based block matching approach is replaced by an image processing based wire detection which needs to be implemented application specific!

2.3 Shadow effects

2.3.1 Problem statement

Directional lighting in the scan scene results in shadows, casted from the wires on the background. Following our recommended setup and using a tubelight, this effect is drastically reduced. However, the illustration in Figure 9 shows that for certain background materials and wires, there exist residual shadow effects.

These shadows become problematic, when image content of a correlation window (the size of a block in block-matching) contains distinct shadows in corresponding regions of right and left image (as shown in Figure 9). In that case, the correlation value is low because the content of the blocks does not match – even though the blocks are in fact corresponding regions of right and left image.

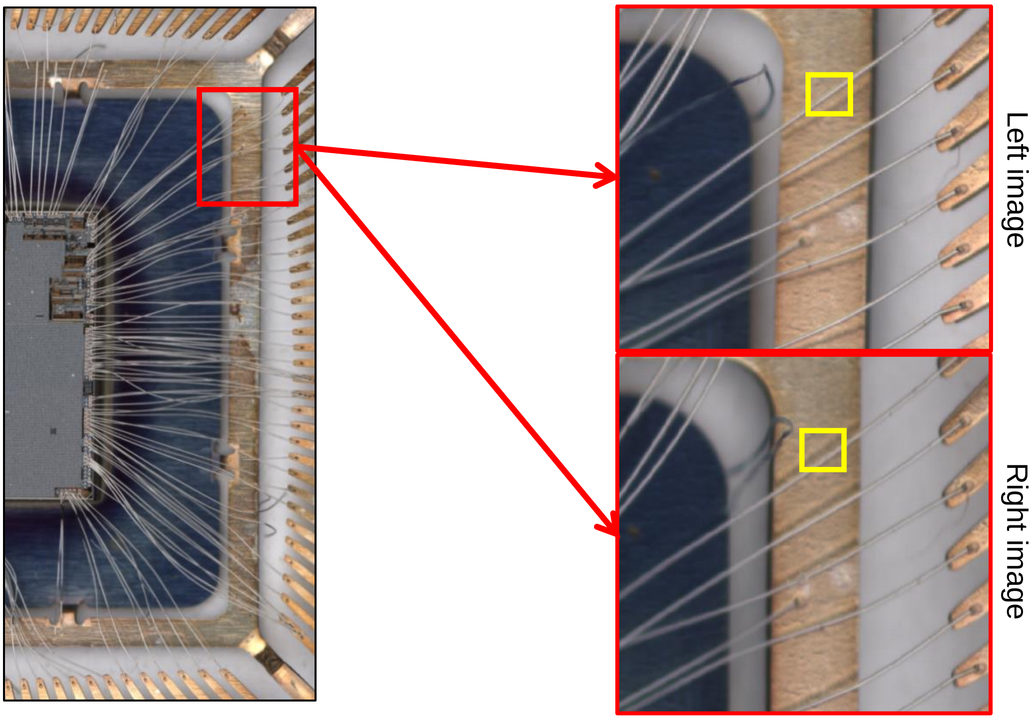


Figure 9: Illustration of shadow effect in left and right image of a stereo pair.

2.3.2 Problem solving strategy

The shadows appear in distinct locations of stereo images because of the perspective difference of right and left view.

One approach to overcome the problem is to improve the scene lighting such that shadow effects are reduced. This is not always possible and might require complex custom made light sources.

An alternative approach is to reduce the correlation window block size. However, the minimum size that can be used has to be selected such that enough unique texture features are remaining for 3D computation in a corresponding window.

At last, image processing can be used to remove the shadows from the stereo image pair, for instance by segmenting the wires from the background, which contains the shadow effect. Once background regions are removed (ie. set to zero value), the configuration of the 3DAPI can be setup such that these regions are ignored in the computation.

3. Summary

The application of 3DPIXA for wirebond inspection was discussed. After introducing considerations and guidelines for vision system design and setup, specific challenges with wirebond inspection were introduced. Each challenging aspect was illustrated by example and the following problem solving strategies were discussed in detail:

Challenge 1: Horizontal wire (see Chapter 2.1)

- Rotate the scan scene such that wires do not appear horizontal in the scan images
- Rotate the camera such that no horizontal wires appear in the scan image
- Project a pattern on the wires to create image texture

Challenge 2: Spacing of parallel vertical wires (see Chapter 0)

- Limit the disparity search range parameter
- Segment and label individual wires prior to 3D computation

Challenge 3: shadow effects (see Chapter 2.3)

- Modify scene lighting to reduce shadows
- Reduce window size for 3D computation
- Remove background by image segmentation