

# HARD- AND SOFTWARE SYSTEMS FOR EVALUATION OF NEW MULTI CHANNEL IMAGE PROCESSING ALGORITHMS

Martin Correns<sup>1,2</sup>, Maik Schumann<sup>1</sup>, Maik Rosenberger<sup>1</sup>, Matthias Rückwardt<sup>1</sup>, André Göpfert<sup>1</sup>, Gehard Linß<sup>1</sup>

<sup>1</sup> Department of Quality Assurance, Ilmenau University Of Technology, Germany

<sup>2</sup> martin.correns@tu-ilmenau.de

G.-Kirchhoffplatz 2, 98693 Ilmenau, Germany

Phone +49 3677 693962, Fax + 49 3677 693823

**Abstract:**

For every new method or technique a certain testing environment is necessary. Tests are required not only for a concluding result of its effectiveness, but for evaluation during research and development as well.

In the department of Quality Assurance at Ilmenau University of Technology one of the fields of research is precision measurement of geometrical features with multi channel image processing systems. One of the biggest challenges is, that the new algorithms for multi channel images (i.e. colour images) can hardly be verified by comparison with well-established algorithms for single channel images.

There are certain influences to the digital image that result in slightly different edge positions in the different channels of one image, i.e. chromatic aberrations of the optical system or small shifts between separate receiver matrices. To develop new algorithms, images without those flaws are necessary. In this paper two different approaches are described to acquire those images. One consists of synthetic images that are designed to have properties that are similar to real camera images. The second approach is to use a special optical system that is free of any chromatic aberrations in combination with single receiver matrix cameras. The goal is to avoid problems from these sources of edge position deviation in the multi channel image. Exemplary results of the research on new algorithms with these testing methods are being presented.

**Keywords:** (image processing testing evaluation measurement)

## 1. INTRODUCTION

Image processing for measurement of geometric features is applied for example in coordinate measurement machines (CMM). The principle operation is to detect coordinate points at the edges of an object and fit the anticipated geometry to a certain number of those points, shown in Fig.1.

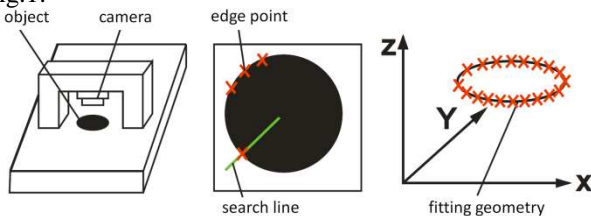


Fig. 1: CMM with image processing

For the process of precision edge probing in digital single channel images there are several different methods [1]. For subpixel precision edge probing in multi channel images there are very few approaches, especially when cross-channel edge information are to be considered. One of

the challenges for research of new multi channel edge probing methods is, that the testing and evaluation of those new methods cannot be done by comparison with their single channel counterparts. In most cases of real images the established criterion of the edge position is not fulfilled at the same coordinates in all the channels, Fig. 2 illustrates this problem.

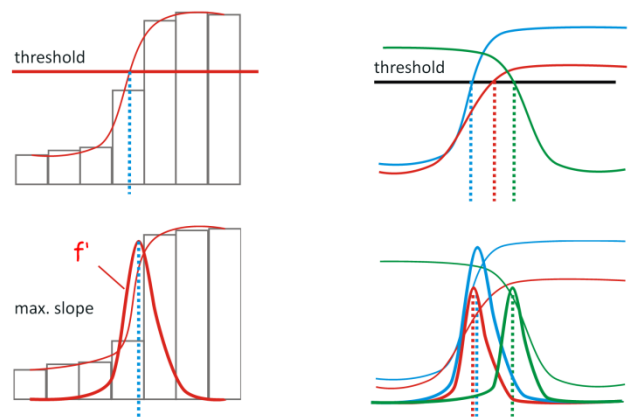


Fig. 2: edge criteria in single and multi channel images

## 2. SYNTHETIC IMAGES

### 2.1 Goals of usage of synthetic images

One possible way to overcome the problem of different edge positions in different channels is to create images with the desired characteristics. There is an additional advantage to this approach. By creating the images by oneself some properties can be set, that normally could not be controlled.

In real camera images the edge positions of objects are unknown. Synthetic images can be created with specified edge positions. In experiments with these images the algorithms examined can be evaluated directly by comparing the specified edge positions to the determined position.

Other properties that can be controlled are the grayscale step in the image that represents the edge and the signal noise ratio (SNR) of the values in the channels. Using a specified noise distribution, i.e. "normal distribution", is an option, to examine how new algorithms cope with these influences.

### 2.2 Creation of synthetic images

To get good results for the synthetic images compared to real images the process of creation of a real image is mimicked by simulation. The creation includes simulation of imaging process of an optical system, sampling of that

image by the cameras sensor matrix and discretisation to a digital image.

The objects intensity function contains a step function that represents the objects edge. The objects intensity function is then convoluted with the point spread function (PSF). Different PSF are possible, a symmetric 2D Gaussian function was used for the experiments presented (Fig. 3). The convolution is approximated by a numeric integration according to Simpson's rule.

$$PSF(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}}$$

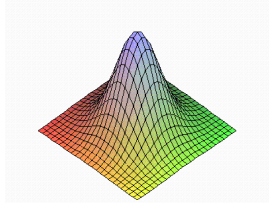


Fig. 3: Graph of a symmetric 2D Gaussian function

$$I_{\text{Img}}(x, y) = \int_{-5\sigma}^{5\sigma} \int_{-5\sigma}^{5\sigma} I_{\text{Obj}}(x - \alpha, y - \beta) \cdot PSF(\alpha, \beta) d\alpha d\beta$$

$$I_{\text{Pixel}}(i, j) = \int_0^1 \int_0^1 I_{\text{Img}}(i + \gamma, j + \delta) d\gamma d\delta$$

The result of the convolution is the intensity function as it would appear on the sensor matrix ( $I_{\text{Img}}$ ), it is the representation for the analog image.

The model for the sensor's sampling functionality is square shaped pixels that are arranged gaplessly next to each other. The integration of the intensity function ( $I_{\text{Img}}$ ) over a pixel's area delivers the pixel's intensity value ( $I_{\text{Pixel}}$ ). In the last step this intensity value is normalized to the target images intensity resolution, i.e. 256 steps or 8 bit in each channel.

Parameters to adjust the synthetic images properties are:

- Dimensions and number of channels
- Gray scale values for each channel, before and after the step that represents the edge
- Width of 2D Gaussian function ( $\sigma$ )
- Edge position
- Angle between pixel grid and edge
- Amplitude of additional normal distributed noise

The shape of the edge in the sample images is a step in one direction and straight line in the other direction. Other object intensity functions ( $I_{\text{Obj}}$ ) are possible.

### 2.3 Example pictures of synthetic images

The following examples have dimensions of 32x32 Pixels and three channels. The series consists of 16 images with different edge angles (Fig. 4). The grayscale steps are: red 200-30; green 30-200; blue 200-30. On a x86 compatible PC with two quadcore CPUs with 2.3 GHz (eight cores in sum) it took approximately 22h to calculate one of these images.

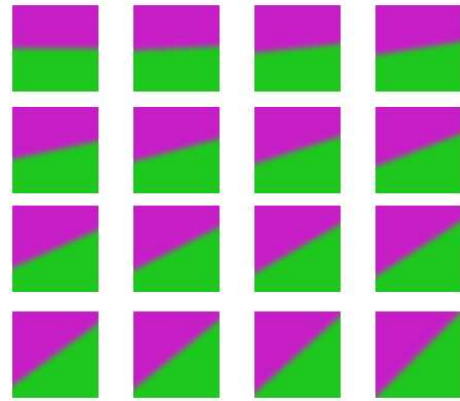


Fig. 4: Samples of the synthetic images

### 2.3 selected results of experiments using the synthetic images

In one of the experiment series the question at hand was how the angle between the pixel grid and the straight edge would influence the newly developed subpixel precision edge probing algorithms.

The procedure was to use a number of search lines orthogonal to the edges, shown in Fig. 5. On each search line one edge point was determined. Every point was compared to its reference position, the differences are plotted in a diagram.

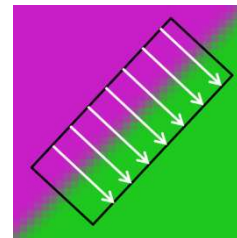


Fig. 5: Arrangement of search lines in the picture

The exemplary comparison consists of three different angles with four different edge probing methods. Three of these are new methods one is an established single channel method.

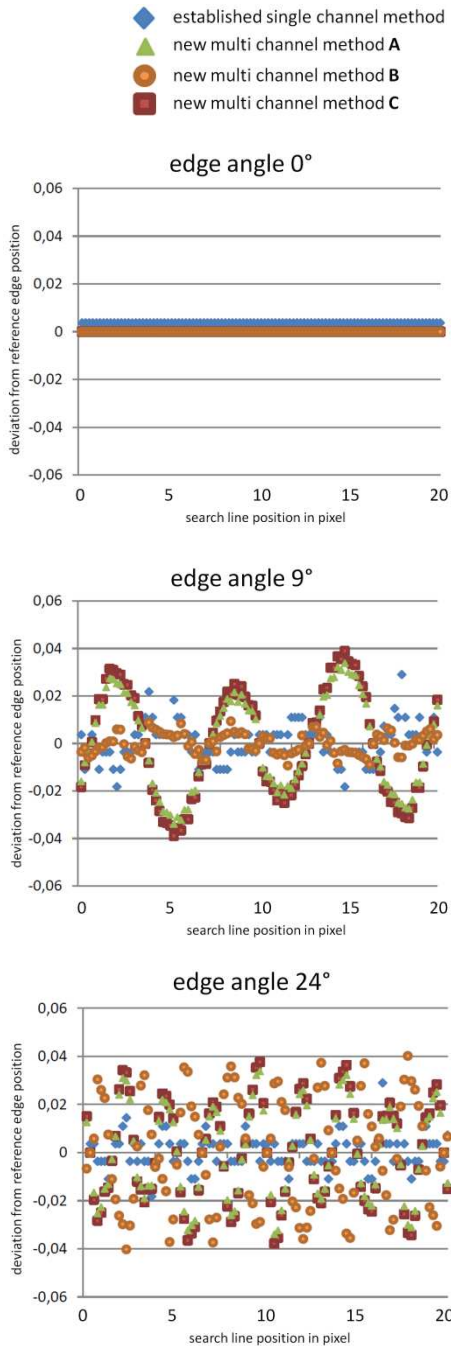


Fig. 6 exemplary results for edge probing experiments

An interesting result from those experiments was, that there are periodic deviations depending on the edge angle to the pixel grid. The frequency gets higher with steeper angles up to a point where the periodic characteristic is not detectable anymore. A possible explanation is that the conversion from the discrete values of the digital image to the discrete values of the search line leads to those periodic deviation. The result for 45° was the same as for 0°. It was almost completely without deviation. All methods are being influenced by this, even the established grayscale method,

but the influence shows different magnitudes for the tested algorithms. In this case, the new method B proves to be less prone for this effect and therefore suitable for further research.

The second experiment is not for an edge probing algorithm but for a preceding image processing algorithm, the demosaicing. Demosaicing is a process necessary to reconstruct three-channel images from sensors with color filter array (CFA). A CFA is a pattern of filters in front of the imaging sensor to distinguish the three different spectral ranges for those channels with in exchange for loss of lateral resolution. For reconstruction (demosaicing) there are numerous different algorithms, very few of which are optimized for the application in measurement of geometric features. Most of them are optimized for human visual perception.

The following diagrams (Fig. 7, 8) show a comparison between a very popular algorithm, the bilinear interpolation and a newly developed method [2].

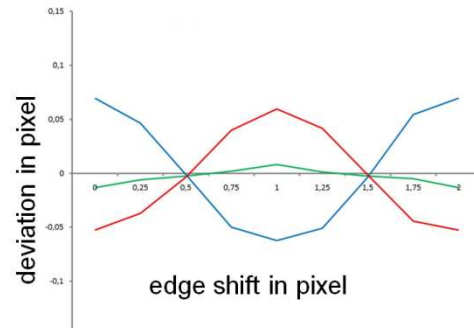


Fig. 7: deviations with new demosaicing method

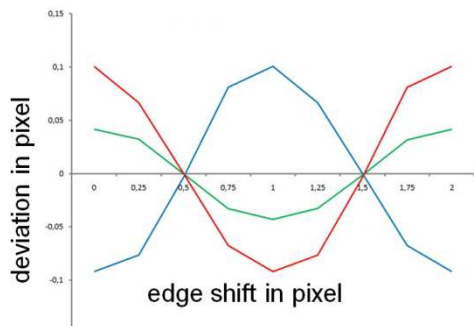


Fig. 8: deviations with bilinear interpolation

The test was conducted with a series of synthetic images with 0° edge angle but different edge shifts (steps of 0.25 pixels). The sampling of the image with a CFA was simulated and two different demosaicing algorithms were applied to reconstruct the images.

At positions 0.5 and 1.5 the reference edge position is in the center of a pixel. Deviations occur only, when the edge is shifted from those positions. It seems to have periodic behavior which is caused by the repeating filter pattern of the CFA. The new method delivers significantly better results than the bilinear interpolation, which is by far the most common demosaicing algorithm in industrial image

processing.

In real camera images the advantage of the method could hardly have been proven. Other influences to the digital image would have "masked" these small differences in edge position. The difference of the new method compared to *bilinear demosaicing* is about  $\pm 1/20$  Pixel. But since every systematic deviation adds to the uncertainty budget of the measurement even small proportions are of interest.

### 3. IMAGING OPTICS FREE OF CHROMATIC ABBERATIONS

The second approach for an experimental environment is to use real camera images but to eliminate the biggest influence to the edge position differences in different channels: Usage of a optical imaging system free of chromatic aberrations.

The synthetic images have a lot of advantages but one major problem. The creation of those images is bound to a model and therefore always just an approximation to the reality. Using a real lens and a real camera for experiments is much closer to the later application of the newly developed algorithms.

In theory it is not difficult to create a optical system without chromatic aberrations. The only requirement is the absence of any elements in the optical path that create colour dispersion. That means no usage of refractive or diffractive elements. It leaves only reflection as light deflecting effect. In conclusion the lens has to be a mirror only design.

In system construction the adjustment is far more difficult for mirrors then it is for lenses. Additionally stray light is a bigger issue and since there is no optical window, the mirrors are exposed to the environment and therefore less protected against dirt.

Concerning measurement of geometric features other properties of the optics are of interest as well. Object and image side should have telecentric ray characteristics. Distortion and field of curvature should be low.

There is an optical design that promises these properties: the "Offner triplet" optical design. It will be the basis to a new lens that is currently being constructed.

Overall the new lens is a challenge for optical and mechanical engineering.

Unfortunately due to technical problems the lens is not finished at the time this paper was written. There are no experimental results yet.

### ACKNOWLEDGEMENTS

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