urn:nbn:de:gbv:ilm1-2011imeko-079:8

Joint International IMEKO TC1+ TC7+ TC13 Symposium
August 31st – September 2nd, 2011, Jena, Germany
urn:nbn:de:gbv:ilm1-2011imeko:2

ANALYSIS AND CORRECTION OF ERRORS OF OPTICAL MEASURING SYSTEMS BASED ON CCD-SENSORS

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Abstract – Nowadays optical measuring systems based on CCD-sensors are widely used. In industry such systems perform measurements with accuracy of 1 µm, but images which are made and processed by systems are always corrupted. This fact can greatly reduce measurement accuracy. It is necessary to perform image pre-processing to avoid this.

The paper presents the results of the study of the influence of measuring system components and system calibration on measurement accuracy as well as a possible way of enhancement of these systems' accuracy. There were investigated systems based on monochromatic and color (both three-sensor and Bayer filter) cameras.

Keywords: image quality, measurement errors, accuracy enhancement

1. INTRODUCTION

Nowadays optical measuring systems based on CCD-sensors are widely used. In industry such systems perform measurements of the set of features of a big amount of components in a short time with accuracy of 1 µm. Images which are made and processed by systems are always corrupted. This fact can greatly reduce measurement accuracy. To avoid this it is necessary to perform image pre-processing.

The purposes of the research were ascertainment of influence of measuring system components and system calibration on measurement accuracy and enhancement of these systems' accuracy. There were investigated systems based on monochromatic and color (both three-sensor and Bayer filter) cameras.

2. ANALYSIS OF IMAGE QUALITY

An optical measuring system consists of an objective lens, a camera, a lighting system, a position control system and software for image processing. Systematic and random errors of such systems as well as the image quality were evaluated.

The following parameters were chosen as characterizing image quality in the suggested fuzzy model for quantification of image quality [1]:

- sharpness – amount of pixels on the threshold of objects;
- noise – arithmetical mean of gray level;
- contrast – difference between maximal and minimal gray levels;
- vignetting – difference between gray levels at the edge and center of images;
- field curvature – difference between sharpness values at the edge and center of images.

All of these parameters are linguistic variables with three possible values: "bad", "normal", and "good". E. g., in case of the linguistic variable "noise" value "good" means that the image has almost no noise. The knowledge base of the set of IF-THEN rules was created after the analysis of both possible ways to use different types of membership functions and the results of experimental studies. There was supposed that the image quality is bad if these parameters have big values and the image quality is good if these parameters have small values or equal to 0.

The quantification of image quality allows to tune a system and to evaluate measurement accuracy on the given image.

3. SHARPNESS IMPROVEMENT

Reference [2] describes a way of edge detection on images via fuzzy logic techniques. Authors have used knowledge base of 8 IF-THEN rules which are illustrated on the Fig. 1. Input variables characterize gray level of the pixel and can be either "black" or "white". Output variable shows if the specified pixel is located on the object edge or not.

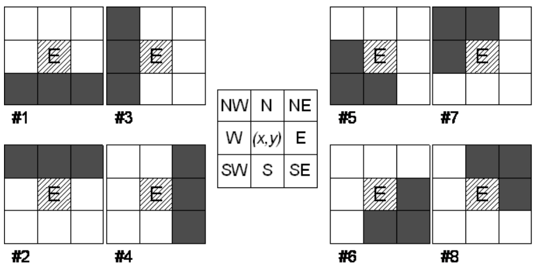

Fig. 1. Edge detection

The same approach was used for processing of images made by optical measuring systems [1]. Possible values of variables are "black" and "white" with Zand S-shaped membership functions respectively. The fuzzy inference system analyzes each pixel of images after that it is assigned a new value of gray level depending on gray levels of 8-connected pixels. Fig. 2, 3, and 4 illustrate the difference between the source image (a) and the resulting image (b); (b)-images are brighter, more contrast and less noisy than (a)-images.

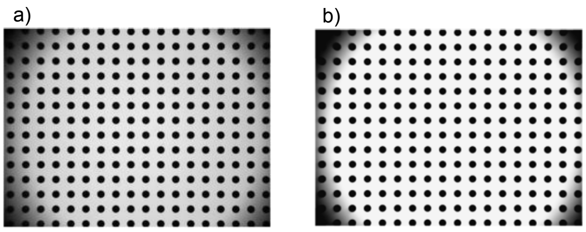

Fig. 2. Source image (a) and resulting image (b)

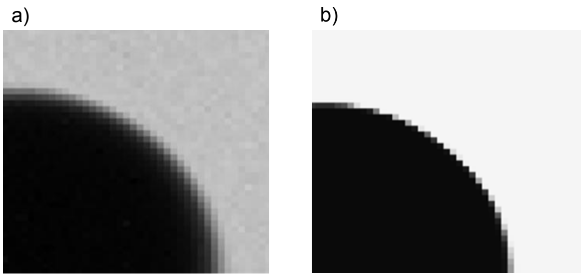

Fig. 3. Source subimage (a) and resulting subimage (b)

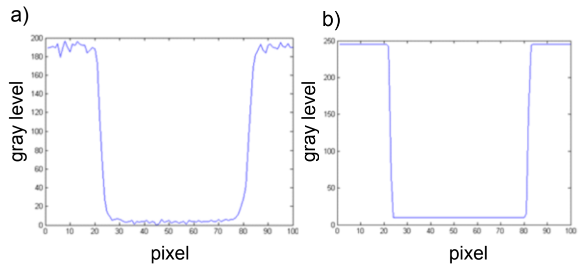

Fig. 4. Brightness functions on objects' threshold before (a) and after (b) image processing

4. SYSTEMATIC AND RANDOM ERRORS

The standard used to define systematic and random errors is shown on the Fig. 5, a. The standard is a glass surface coated with circles (Fig. 5, b) which have positions specified with accuracy of 0.15 µm.

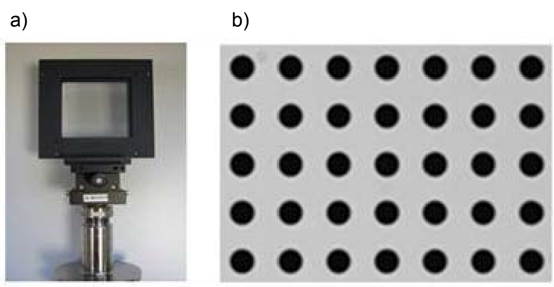

Fig. 5. Standard (a) and its image (b)

Coordinates of circles centers were fixed and compared with the standard documentation.

18 different optical measuring systems were investigated and it was found that random errors were less than 1 µm, systematic errors usually were 20-60 µm. In other words, theoretically, features of objects can be measured with accuracy of much less than 1 µm, but optical systems corrupt images and this fact is the reason of significant measurement errors. Systematic errors of different optical measuring systems are shown on the Fig. 6.

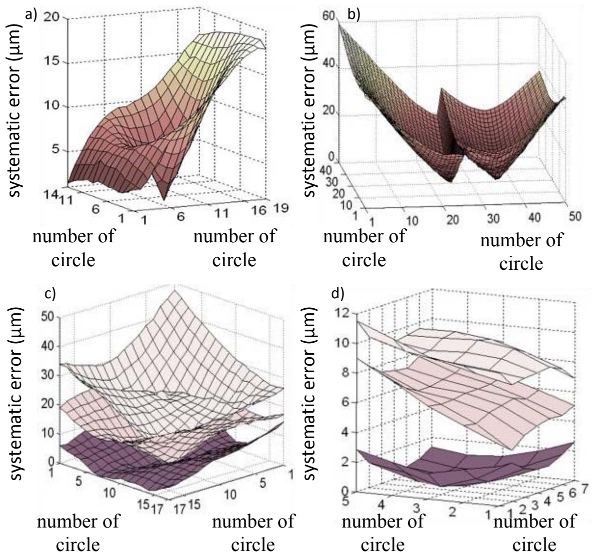

Fig. 6. Systematic errors of systems based on a monochromatic camera with one (a) and two sensors (b), a color three-sensor camera (c), a color camera with the set of Bayer filters (d)

Systematic errors are changed abruptly at the border and have asymmetrical shapes in case of a monochromatic camera with two sensors. Systematic errors of systems based on a color three-sensor camera may differ in every channel. Systematic errors of systems based on a color camera with the set of Bayer filters are shifted relative to each other and only one surface is located near 0. In addition, during the research were registered the following facts [2]:

- Objective lenses largely determine the shape and size of systematic errors.
- Cameras largely determine the value of random errors.
- Image processing software influences both on systematic and random errors.
- Lighting changes resulted in increased systematic errors from 10% to 25%
- The size and position of the chosen standard significantly change the shape and value of systematic errors (during the research up to 50%) and had no significant influence on random errors.
- Also, it is ascertained that in case of color cameras the chosen for calibration channel significantly changes the shape and value of system-

atic errors (the maximal systematic error could move to the border of the image) and has no significant influence on random errors.

5. 3D DEPENDENCE OF ERRORS

3D dependence of errors which was also investigated for systems with telecentric objective lenses (a) and with not-telecentric objective lenses (b) is shown on the Fig. 7.

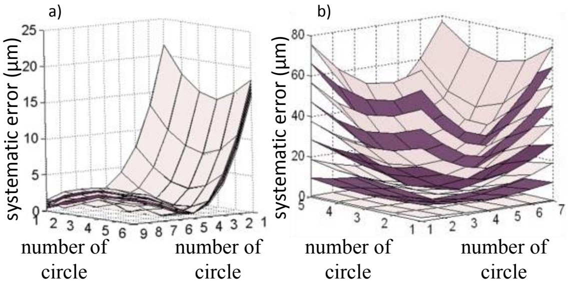

Fig. 7. 3D dependence of errors of systems with telecentric objective lenses (a) and systems with not-telecentric objective lenses (b)

Systematic errors of systems with telecentric objective lenses can be described within 2D or 3D surface, while systematic errors of systems with not-telecentric objective lenses can be changed when the objective is moving and therefore such errors can be described within 3D space.

In some cases of usage telecentric objective lenses it is enough to perform 2D correction [3], but for other cases (usage of not-telecentric objective lenses, enhancement of measuring systems accuracy with telecentric objective lenses) 3D correction is more preferred.

During the research some possibilities of accuracy enhancement of optical measuring systems by 2D and 3D correction of systematic errors were described as well. Finally, the following ways were suggested for enhancement of optical measuring systems accuracy:

1. Correction of measurement data (does not modify images)
2. Correction of geometric distortion of images

These two ways were used for different systems based on a monochromatic camera, a color three-sensor camera, and a color camera with the set of Bayer filters.

An example of corrected measurement data for a system based on a monochromatic camera using 2D model is shown on the Fig. 8. At first, the maximal systematic error at the border of images was 19 µm (a), after the correction it was less than 0.5 µm (b).

At first, the maximal systematic error at the border of images was 19 µm, after the correction it was less than 0.5 µm.

In general, systematic errors of the researched measuring were reduced systems by the correction of measurement data from 20-200 µm to 1-2 µm after the correction.

Color images are distributed by the correction of geometric distortion of images into 3 monochromatic images when correcting obtained, e. g. from a system based on a color camera with the set of Bayer filters, images. Each channel has its own geometric distortion; therefore at first each image is corrected separately, then these 3 monochromatic images are combined into one color image.

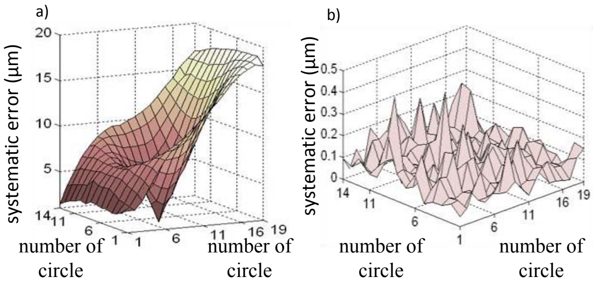

Fig. 8. Systematic errors of a system based on a monochromatic camera before (a) and after (b) the correction using 2D model

A subimage (a circle of the standard) before and after the correction of a system based on a color three-sensor camera is shown on the Fig. 9.

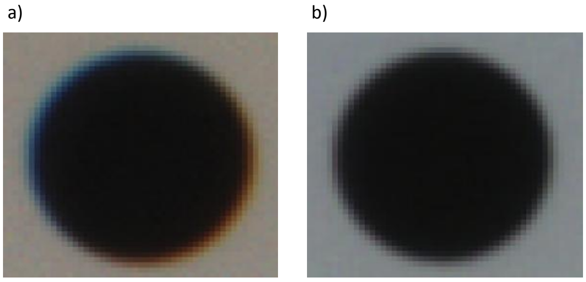

Fig. 9. A circle of the standard before (a) and after (b) the correction (a system based on a color three-sensor camera)

Systematic errors before and after the 2D correction of geometric distortion are shown on the Fig. 10.

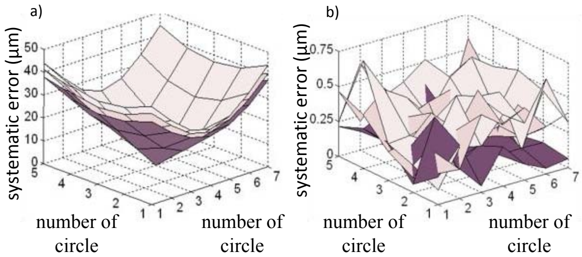

Fig. 10. Systematic errors of a system based on a color three-sensor camera

Maximal systematic errors for the red channel were 42 µm, for the green channel were 40 µm and for the blue channel were 38 µm (a). Maximal systematic errors for modified images (after the correction) were less than 1 µm (b).

Also the correction was performed for systems based on a color camera with the set of Bayer filters. Such systems register 25% of blue color, 25% of red color and 50% of green color. The process of restoration levels for other pixels has own drawbacks and problems, therefore images of each channel are processed in RAW-format. To merge 3 channels into 1 all blue and red and only a half of green pixels are used; pixels are moved to a midposition. Again, each image is corrected separately, and then these 3 monochromatic images are combined into one color image.

A subimage (a circle of the standard) before and after the correction of a system based on a color camera with the set of Bayer filters is shown on the Fig. 11.

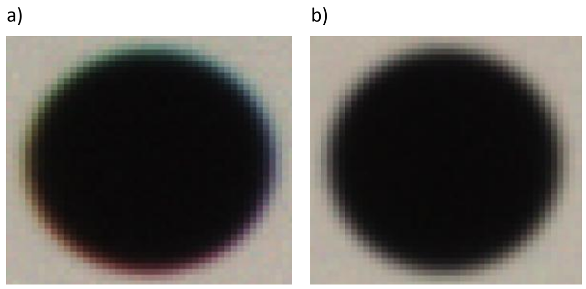

Fig. 11. A circle of the standard before (a) and after (b) the correction (a system based on a color camera with the set of Bayer filters)

Systematic errors before and after the 2D correction of geometric distortion of images are shown on the Fig. 12.

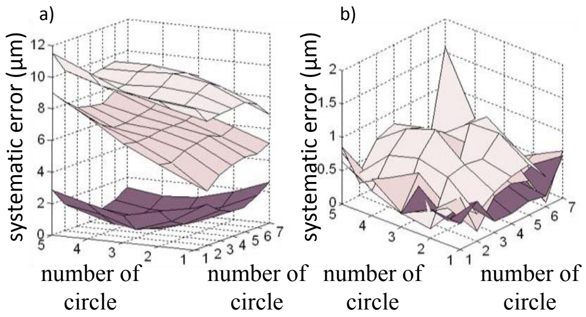

Fig. 12. Systematic errors of a system based on a color camera with the set of Bayer filters

Maximal systematic errors for the red channel were 12 µm, for the green channel were 9 µm and for the blue channel were 3 µm (a). Maximal systematic errors for modified images (after the correction) for the green and blue channels were less than 1 µm, for the red channel were about 1.6 µm (b).

6. CONCLUSION

During the research some possibilities of accuracy enhancement of optical measuring systems by 2D and 3D correction of systematic errors were described. Also, a new method of quantification of image quality based fuzzy logic techniques, correction of measurement data, and precise correction of the geometric distortion of images were suggested as additional methods to improve accuracy.

ACKNOWLEDGEMENT

The presented work is the result of the close cooperation with the following co-workers of Quality Assurance and Industrial Image Processing Department: Carl-Bernhard Nopper, Rolf Hoffmann, Klaus-Jürgen Rennert, Dr. Peter Brückner and Dr. Thomas Ortlepp. The research was supported by German Academic Exchange Service (DAAD), the Ministry of Education of Russian Federation and Thüringer Aufbaubank.

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