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Bayesian model for subpixel uncertainty determination in optical measurements

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Abstract

Uncertainty determination can be obtained by two procedures: GUM and the Monte Carlo Method. This work presents a model that helps to evaluate the uncertainty in measurements collected by optical measuring machines when using the Monte Carlo method. Initially, the model converts intensity, using Bayesian probability, from the pixel image derived from camera into a polygonal area with three to five vertexes. The outer vertexes are fitted using least squares procedures to obtain a measurand shape approximation in a subpixel range. Algorithms have been programmed and verified into Matlab using synthetic images with different triangles. Through a detailed analysis, the usefulness of a new tool, the parameter, will be demonstrated as an alternative method for estimating uncertainty of measurements of pixel images.

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*Keywords:*subpixel approximation, bayesian probability, optical measurement, uncertainty, Monte Carlo method.

1. Introduction

Nowadays, vision machines are a real alternative to achieve measurand characterization in a submillimetre range. These machines's speed in obtaining measurements, their lack of need of physical contact and automation has earned them a prominent place in current metrology, thus generating a considerable scientific interest oriented towards

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optimizing their operation, especially regarding estimates in uncertainties of measurement. Scientific research in the field of optical metrology has grown in last decade. [1-4]. Nowadays, modern optical equipment can provide a three-coordinate measuring machine, CMM, which already has a standard model developed for measurement. This paper proposes stripping off the Z-axis and using parameter in order to simplify the problem of uncertainties of measurement by performing them in two dimensions. Since the digital optical equipment can produce other sources of uncertainty a specific study will be required which will be accounted for in this paper as well.

An optical instrument of measurement can be divided into two parts: as a machine and as an optical system. The machine is a monobloc structure that is supported by the table and allows for measuring by the displacement of the shafts. The optical system is made up of a complex set of lens and devices, such a CCD sensor, which allows the acquisition and transfer of images to the computer. Therefore, CCD camera replaces the "system of contact of the probe" used in a conventional CMM. This division of machine parts allows for the separate analysis of both systems to obtain a simplified model as a basis for the evaluation of the uncertainties of measurement [5-7]. In order to carry out the study of a complex optical model, all of the inner physical properties of lenses and devices should be known. Although due to the complication of this task, this type of study has been disregarded as a possibility in this paper but could be taken into account for future studies. Additionally, the pinhole camera [8, 9] is an alternative model which can be taken into account the amplification and radial and tangential distortions [5, 6].

The new model is based in former procedures, supposing that the optical system is well designed; and the image that CCD receives is a close representation of measurand. The first hypothesis assumes that these geometric variations come from information losses of reflected light in measurand and subsequently guided into optical device, when it is converted in CCD sensor. Therefore, a possible way to represent previous process is modelled such as the transformation from a real number to a natural one, i.e, areas are transformed into intensities. In this paper this conversion is defined as the direct method, and the inverse process from image pixel intensities to areas and edge coordinates, the reverse method. This method and partial area effect share main idea to acquire an accurate edge location [12]. The direct method is mainly used in this paper to generate synthetic images to uses as pattern in verifications tests.

Subpixel algorithms give an extra accuracy in measurements although they use to need an extra computing time. The above algorithms output, from the image segmentation, the measuring edges obtained in subpixel range as a set of coordinates in a plane. If the measurement uncertainty is estimated by the Monte Carlo Method, supplement 1 of the GUM [13], some probability density function, PDF, will have to be defined. This task will be done by the proposed 3x3 pixels geometric model that takes into account the behaviour of central pixel and their first neighbours. Afterwards using the Bayesian probability as data filter, all PDFs will be saved in a database to speed up the algorithms that later could be used in the Monte Carlo method. The validation of the proposed method will be carrying out using synthetic triangle images generated by the direct method and fitted by least squares [14, 15].

2. Code and execution time

All code described in this paper are compiled in Matlab. Some models, mainly the 3x3 pixels model, need an extra computing time about 60 hours, so this code is evaluated using the CeSViMaMagerit Supercomputer. The Magerit supercomputer is a general purpose cluster with dual architecture, Intel and POWER that covers most computing needs. The POWER configuration is able to provide sustained power of more than 72 TFLOPS over a theoretical peak of almost 103.5 TFLOPS. The Intel partition provides a sustained power of more than 14.8 TFLOPS over a theoretical peak of 15.9 TFLOPS. After data base is generated all algorithms can be run in a i7 processor laptop with 12 Gb of RAM under Linux. The proposed procedure and others which were compared need almost the same run time amount.

3. The direct method

One of first CCD model description due to Janesick and Blouke [16] uses a *"rain to bucket"* physical simile. Using this idea is supposed that the camera CCD outputs are proportional to the light reflected from measurand and guided through optical devices. Under other point of view, if the measurand image is formed in focal plane of optical devices, just in front the CCD sensor, the output image pixel intensities will be proportional to the area that is