IMPROVED ALGORITHM FOR CALCULATING GEOMETRIC CHARACTERISTICS FROM OPTICAL IMAGES OF CORRODED OBJECT'S CROSS-SECTION

Borislav Bonev

Department of Microelectronics, Technical University of Sofia
8 Kliment Ohridski Blvd., Sofia, Bulgaria
T. +359876432090; E-mail: bonev@ecad.tu-sofia.bg

Anna Stoynova

Department of Microelectronics, Technical University of Sofia
8 Kliment Ohridski Blvd., Sofia, Bulgaria
T. +359882142522; E. ava@ecad.tu-sofia.bg

Antonio Shopov

Department “Mechanics and Mathematics”, VSU “Luben Karavelov”
175 Suhodolska str., Sofia, Bulgaria
T. +359878930570; E. shopoff@mail.bg

Abstract

The paper proposes improvements of previously proposed by authors method for automated calculation of second area moments of random complex cross-sections by using digital images. The method is optimized for determination of corrosion impact on geometric characteristics of random cross-sections. The comparison between the method and other methods is presented for verification of the obtained results. It is studied the impact of the image’s resolution on method accuracy.

1. INTRODUCTION

In modern engineering practice, various metrics can be determined by the use of digital images. Ways to determine the moment of inertia of a section have been developed [3, 7]. Although the formulas for the corresponding calculations are known, their precise calculation is still fraught with the corresponding calculation errors due to many factors. Engineering staff uses graphical computing software (such as AutoCAD for example) where it is possible to calculate geometric characteristics by using cross-section photo material. In these methods it is required to draw a given area or figure, to draw in the so-called “region" and from there the program can perform the calculation. This method significantly increases the possibility of errors and inaccuracies.

Usage of optical digital images in analysis and classification of materials is well studied [1-7]. Publication [7] proposes a method for determining second area moments using a digital image. This approach is sufficiently reliable and accurate in cases where the section has an axis of symmetry. In corrosion sections, the methods needs to be improved, since corrosion propagates arbitrarily, not symmetrically, and using the theory, there should be the product moment of inertia different from zero [8-9]. For this reason, the possibility to calculate the principal axes of moment of inertia and rotate them to determine the maximum and minimum moment of inertia has been added. In [7], the image is segmented into two regions – region with area and region without area. This article proposes to segment three regions – solid material, empty areas and corrosion areas.

2. BASIC THEORETICAL METHOD

In [7], the proposed method uses the representation of image constituent pixels as a geometric figure with corresponding geometric characteristics (fig. 1), on the basis of which the moment of inertia is calculated:

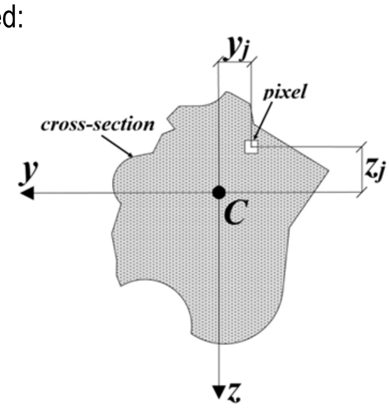

Figure 1. Basic concept for determination of pixel second area moment [9]

For figures without an axis of symmetry, the product moment of inertia is calculated by the formula [8-9]:

$$I_{yz} = \iint_A y.z\, dA \qquad (1)$$

It should be noted that the product moment of inertia could be: positive, negative or zero (in the case of an axis of symmetry). Fig. 2 shows the basic concept for determining axial moments of inertia and principal moments of inertia.

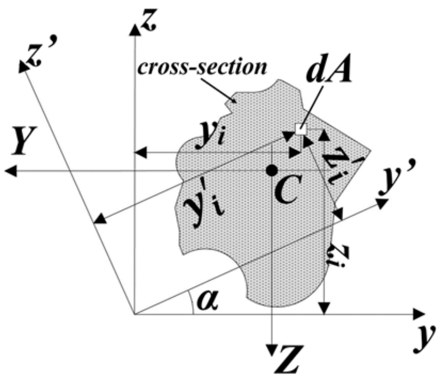

Figure 2. Basic concept of moments of inertia about inclined axis [9]

With known formulas for rotating the coordinate axis [9]:

$$I_{y'} = \frac{1}{2}.\left(I_y + I_z\right) + \frac{1}{2}.\left(I_y - I_z\right).\cos 2\alpha - I_{yz}.\sin 2\alpha, \qquad (2)$$

$$I_{z'} = \frac{1}{2}.\left(I_y + I_z\right) + \frac{1}{2}.\left(I_y - I_z\right).\cos 2\alpha + I_{yz}.\sin 2\alpha, \qquad (3)$$

$$I_{y'z'} = \frac{1}{2}.\left(I_y - I_z\right).\sin 2\alpha + I_{yz}.\cos 2\alpha \qquad (4)$$

the extreme values of the axial moment of inertia can be determined using this requirement [9]:

$$\frac{dI_{y'}}{d\alpha} = 0 \qquad (5)$$

By making the appropriate transformations, the following formula is obtained [9]:

$$\tan 2\alpha = \frac{2.I_{yz}}{I_z - I_y} \qquad (6)$$

This equation has infinite number of solutions. Assuming α_1 is one of them, all others can be expressed by the formula [9]:

$$\alpha_{k+1} = \alpha_1 + k.\frac{\pi}{2}, \qquad (7)$$

where κ = 1,2,3,4,5,6……..n.

If the latter formula is used, it represents two different principal axes that are mutually perpendicular. We denote these axes as y 'and z', as well as other authors [9]. Then they become principal axes of moment of inertia and for them is valid the following equation for every α1 [9]:

$$I_{y',z'} = \frac{(I_y + I_z)}{2} \pm \sqrt{\left(\frac{I_y - I_z}{2}\right)^2 + I_{yz}^2} \qquad (8)$$

From the moment of inertia obtained, one is maximum and the other is minimum. The maximum is denoted I_1 and the minimum is I_2 and they can determined by the formula [9-10]:

$$I_{1,2} = \frac{(I_y + I_z)}{2} \pm \sqrt{\left(\frac{I_y - I_z}{2}\right)^2 + I_{yz}^2} \qquad (9)$$

This classical equation can be used for verification [9-10]:

$$I_1.I_2 = I_y.I_z - I_{yz}^2 \qquad (10)$$

Obtaining a zero for the product moment of inertia for a pair of axes means that these axes are principal axes of moment of inertia and if a figure with arbitrary corrosion products position has an axis of symmetry, then this axis is one of the principal axes of moment of inertia.

3. SOFTWARE IMPLEMENTATION OF THE METHOD

The presented method requires an enormous number of calculations with high performance. MatLab was chosen as the environment for the implementation of the proposed method. The software implementation is based on the algorithm presented in our previous study [7] with several major improvements:

- image segmentation into three areas – solid area, corrosion area and empty area (voids, holes, etc);
- determining the principal axes and moments of inertia;
- automatic visualization of principal axes of moment of inertia axes and coordinate systems;
- greater degree of automation of the calculation process.

Image segmentation is necessary in order to be able to examine sections where both areas with corrosive products and areas without solid material are present (e.g. holes). Image segmentation is realized by well-known method of image binarization [7].

The calculation process is highly automated. The user is required only to define the section outside contour, as well as to measure and enter only one physical dimension of the section.

The calculation of the center of gravity is carried out by the following equations [7]:

$$Z_C = \frac{\sum_{i=1}^{N_{solid}} A_{pixel} z_i}{N_{solid} A_{pixel}}, \quad (11)$$

$$Y_C = \frac{\sum_{i=1}^{N_{solid}} A_{pixel} y_i}{N_{solid} A_{pixel}}, \quad (12)$$

$$z_i = (l_c - l_i + 0.5) a_{pixel}, \quad (13)$$

$$y_i = (c_i - c_c + 0.5) a_{pixel}, \quad (14)$$

where l_c, c_c – coordinates of the origin of the cross-section coordinate system; l_i, c_i – coordinates of an arbitrary pixel from the cross-section area, N_s – number of the pixels, representing areas with solid material.

The moments of inertia I_1 and I_2 are calculated as follows [9]:

$$I_{z_{solid}} = \sum_{i=1}^{N_{solid}} \left(\frac{a_{pixel}^4}{12} + A_{pixel} y_i^2 \right) \quad (15)$$

$$I_{y_{solid}} = \sum_{i=1}^{N_{solid}} \left(\frac{a_{pixel}^4}{12} + A_{pixel} z_i^2 \right) \quad (16)$$

$$I_{yz_{solid}} = \sum_{i=1}^{N_{solid}} A_{pixel} yz \quad (17)$$

$$z_i = (l_i - l_c + 0.5) a_{pixel} + Z_{C_m} \quad (18)$$

$$y_i = (c_c - c_i + 0.5) a_{pixel} + Y_{C_m} \quad (19)$$

The determination of the principal moments of inertia and the angles of rotation of the coordinate system are determined after completion of the calculations described above, on the basis of the formulas presented in section 2.

4. METHOD VERIFICATION

To verify the proposed method, the geometrical characteristics of a section were calculated. The drawing of the section is shown in fig. 3. Based on the drawing, a high-resolution bitmap image (the section region of image is formed by 10,000,000 pixels) was made. The proposed method was applied to this image.

A manual calculation of the geometric characterristics of this section is presented in [10]. Table 1 presents the values obtained by manual calculation and compared with those obtained by the proposed method. The error of the values calculated by the proposed method is calculated.

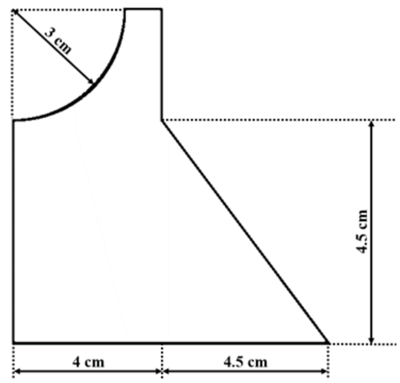

Figure 3. Diagram of the cross-section used for verification [10]

It can be seen that the accuracy of the proposed method is very high if the resolution with which the section is presented is high.

Table 1. Results from verification of the proposed method

	calculation given [10]	proposed method	error [%]
Z_C [cm]	3.167	3.167	0%
Y_C [cm]	3.235	3.235	0%
I_z [cm^4]	155.7	155.7	0%
I_y [cm^4]	200.9	200.9	0%
I_{yz} [cm^4]	-43.17	-43.18	0.0232%
I_1 [cm^4]	227.03	227.05	0.0088%
I_2 [cm^4]	129.57	129.58	0.0077%
α_1 [deg]	31.183	31.189	0.0192%
α_2 [deg]	-58.814	-58.811	0.0051%

Fig. 4 shows the generated image with plotted coordinate systems. The legend is as follows:

cyan – y-coordinate of the section's coordinate system;

magenta – z-coordinate of the section's coordinate system;

blue – y-coordinate of the translated coordinate system;

red – z-coordinate of the translated coordinate system

green – first principal axis of moment of inertia defining the direction of maximum moment of inertia I_1

yellow – second principal axis of moment of inertia defining the direction of minimum inertia moment I_2

α – angle of rotation relative to the coordinate system between horizontal axis and maximum moment of inertia I_1

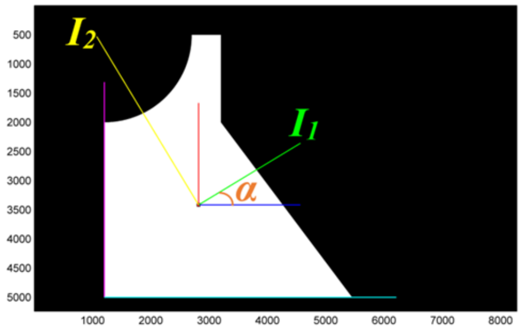

Figure 4. Coordinate systems of the cross-section, used for verification

5. STUDY THE IMPACT OF IMAGE RESOLUTION ON CALCULATION ACCURACY

The study in section 4 was carried out with high resolution image. A study was performed with reduced image resolution in order to determine the effect of the image resolution on the accuracy of the calculation. Fig. 5 shows the dependence of calculation error from number of section's pixels.

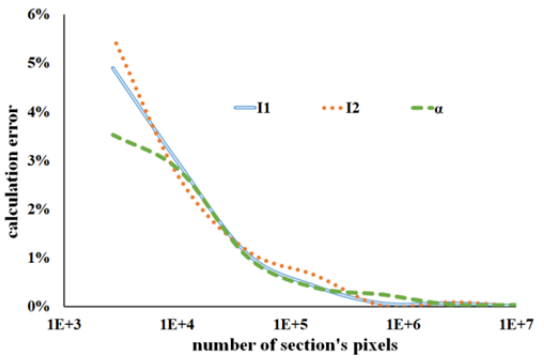

Figure 5. Dependence of calculation error from number of section's pixels

It can be seen that the calculation error is below 1 % for number of section's pixels larger than 100 000. Respectively section image with resolution larger than 0.3 megapixel (the section should occupy as much of the image as possible.) will be enough for calculation with error below 1 %.

6. USING THE METHOD FOR SECTION WITH CORROSION

After the method has been verified, it has been applied in calculating the geometrical characteristics of a section with corrosion. The shape of the corrosion products on the surface is random and therefore manual calculation is practically impossible. Image used for the calculation is shown in Fig. 6. The image resolution is 5936 × 4144 (24 megapixels). The section area contains 9.5 megapixels.

Figure 6. Photograph of the cross-section with corrosion used for calculation with proposed method

A comparison of the obtained results was made using the AutoCAD software. A method with AutoCAD is widely used in practice for calculation of geometric characteristics. Classically, this method requires the manual enclosure of areas for which the geometric characteristics are calculated. For case of image of section with corrosion such as used in this case, this manual enclosure is an extremely slow and difficult process. The image with hand-drawn lines in the environment of AutoCAD software is shown in Figure 7. Table 2 presents the results obtained by calculation using AutoCAD and proposed in this paper method.

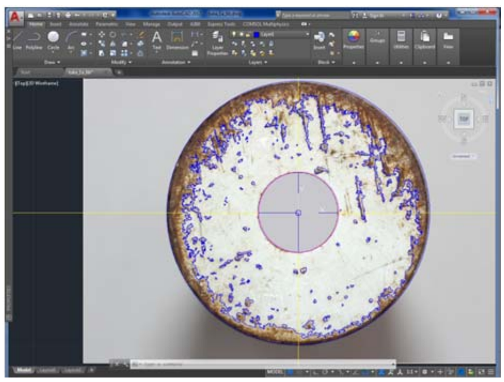

Figure 7. Using AutoCAD for geometric characteristics calculation

Table 2. Results from geometric characteristics calculation of the cross-section with corrosion

	AutoCAD calculation	proposed method	difference [%]
Z_C [cm]	3.80	4.62	13.80
Y_C [cm]	4.13	5.042	18
I_z [cm^4]	316.55	263.29	20.23
I_y [cm^4]	343.19	270.74	21.11
I_{yz} [cm^4]	-23.09	-16.38	29.06
I_1 [cm^4]	356.63	283.813	20.41
I_2 [cm^4]	303.22	250.216	17.48
α_1 [deg]	29.95	38.595	22.40
α_2 [deg]	-60.00	-51.406	19.45

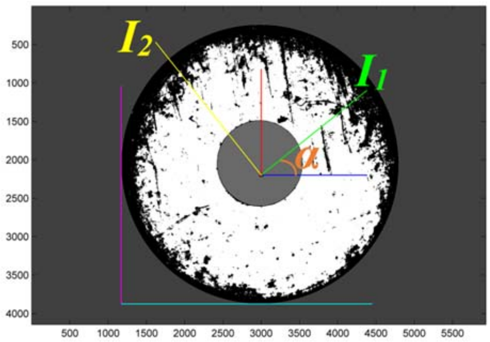

Figure 8. Coordinate systems of the cross-section with corrosion (diameter is 10 cm, image binarization with trace hold 0.65) is used for verification

7. CONCLUSION

The developed algorithm and calculation method are characterized by great versatility, reliability and accuracy.

The algorithm proposed in this article makes it possible to calculate the geometric characteristics of cross sections with the presence of corrosion products on the surface, where the classical methods are inapplicable or would be very difficult to implement them. For comparison, the method proposed in this article requires no more than a few minutes to apply, whereas the hand-drawing method with AutoCAD used for comparison takes days for complex sections.

The difference between the results obtained by AutoCAD and the method in this article are due to major imperfections in the algorithms used. AutoCAD uses vector graphics rather than raster graphics, so the following prerequisites exist:

- The section to be analyzed must be the only section in the drawing;
- The section must be hatchable;
- Can only process lines, arcs, polyline, splines, circles or ellipses are supported if created with pellipse;
- Breaks down the section into component areas or slices. More slices means greater accuracy. The maximum is limited;
- Set desired accuracy, decimal places, conversion units, and units of measure;
- When we have an optical image manual enclosing method and the imperfections of the human eye.

With this method, the segmentation and the entire computation process is automatic. This in addition to the verification results, justifies that the method to be considered more reliable.

The developed method can be applied outside the field of study of the corrosive influences and it is precise enough to be used in other areas, where it is used digital images, e.g. medical imaging.

8. APPENDIX AND ACKNOWLEDGMENTS

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