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AUTOMATED IMAGE PROCESSING USING MAGNETIC DEFECTOSCOPY

Anatoly Grigorevich Korobeynikov, Aleksanin Sergey Andreevich and Oleg Arcad'evich Perezyabov
Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, St. Petersburg, Russia
Email: science-journal@mail.ru

ABSTRACT

To identify defects, for example, cracks in the surface layers of steel parts, methods are applied that base on the analysis of magnetic field dissipation nearby the defects after magnetization of these parts. Magnetic flux will vary in the areas with discontinuity. Magnetic particle inspection is one of the best known magnetic defectoscopy methods. In this case magnetic particle powder (dry method) or suspension (wet method) is applied on the magnetized part surface. Usage of fluorescent powders or suspensions makes defects more easily seen in the images of the inspected parts. Therefore, it becomes possible to carry out automated processing of such images. The paper presents automated procedure for selection of the image processing methods. It exemplifies image processing for a steel part with a view to defect detection with the help of luminous lines appearing after the wet method application.

Keywords: magnetic defectoscopy, image processing, image enhancement, morphological image processing.

INTRODUCTION

When solving the problem of defect finding in the surface layers of steel parts, it is a rather common practice to apply methods based on the analysis of magnetic field dissipation around defects after magnetization of these parts (Sosnin, 2008). In the local area where discontinuity is present, magnetic flux variation occurs. The picture of magnetic field distribution will be determined by the depth of defect occurrence, its size and form. For example, surface cracks oriented perpendicular to the magnetic flux manifest pronounced magnetic field dissipation. Whereas defects oriented along the magnetic flux show practically no field dissipation (Isaev, 2013).

Magnetic particle inspection is one of the best known methods of magnetic defectoscopy (ISO 9934-1:2001). In this case magnetic powder (dry method) is poured or magnetic suspension (wet method) is applied on the surface of the magnetized part (Shelikhov and Glazkov, 2011). Magnetic particles of the powder or suspension getting in the magnetic field dissipation zones will settle on the part surface in the defect occurrence areas.

When using magnetic defectoscopy, circular magnetization is the basic procedure. Longitudinal magnetization is applied usually when it is supposed that the part under study has strictly transverse defects, or application of circular magnetization is unacceptable (Shelikhov, 2010).

Usage of fluorescent powders or suspensions makes defects more easily seen in the images of the inspected parts (Isaev, 2013). Therefore, it becomes possible to carry out automated processing of such images (Gonzalez, 2008; Konushin, 2013). The paper presents development of the automated procedure for the image processing methods with a view to defect detection.

Selection of Image Enhancement Method

Problem solving for automated selection of image processing methods starts from the input of the digital photo of the test part (Shelikhov, 2010; Gatchin, 2015). Nowadays colored photographs are used, as a rule (Gruzman, 2000).

It is a common practice to define an image through the two-dimensional function $f(x, y)$, where x and y are spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called intensity or gray level of the image at the point with these coordinates. Word combination "*gray level*" is often used to denote brightness of a monochrome image. Colored images are formed by combining several monochrome images. For example, in the RGB color system colored image is constructed from three individual monochrome components (red, green and blue). For this reason numerous methods and techniques developed for monochrome images may be extended to the color images by sequential processing of three monochrome components.

A photograph of a flange welded onto pipe will be processed as an example of an image in this paper (Figure-1). This steel part was treated with Magnaglo 14HF fluorescent suspension that created fluorescent green indication pattern, observed in the UV-light at a wavelength of 365 nm. The place of the flange weld onto the pipe is of the greatest interest.

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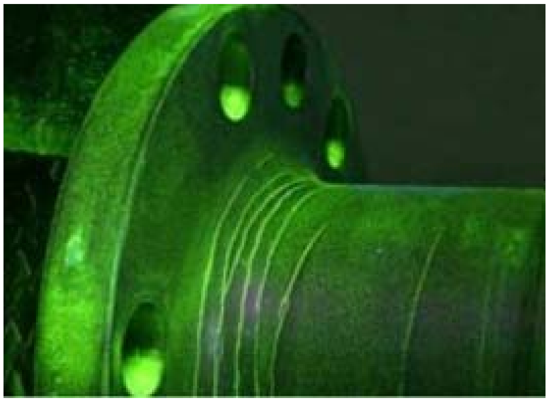

Figure-1. Initial image of the pipe-welded flange.

After image loading it is required to make decision on its quality enhancement (Grishentsev, 2014). This is connected with the fact that reliable identification of defects directly depends on the quality of the analyzed image (Krasilnikov, 2009). Low quality may result in invalid identification or in false determination of defect properties (Krasilnikov, 2011). In this connection the reliable quality in enhancement of similar images is an important task to be solved in low contrast and sharpness conditions of images (Jahne, 2005).

There is no common theory of image enhancement. If an image is processed for the purpose of visual interpretation, the quality of a definite method operation is estimated finally by the operator-researcher. Image enhancement methods are so diverse and use so many different approaches to image processing, that it is difficult to collect meaningful set of appropriate enhancement techniques in one article, without making a separate extensive study (Tschumperle, 2006).

The term "image denoising" is used often enough for image enhancement, implying not only the noise and interference removal or compensation, but also directs extraction of information about the properties of locally heterogeneous objects from the image (Ce Liu, 2008).

It is necessary to take into account that image enhancement methods often result in distortion of information about the objects shown in these images, for example, contrast enhancement and edge enhancement may lead to the distortion of the shape and size of the defectoscopy object, which is unacceptable.

A possible alternate solution to this problem is to use denoising techniques rather than image-enhancement methods for the desired signals, which in this case should be understood as image defects. The signals reflected by the defects can be interpreted as local inhomogeneities of the final two-dimensional non-stationary stochastic signal. Then there is a task of filtering local inhomogeneities of images on the noise background (Voskoboinikov, 2007, Fisenko V.T. and Fisenko T.Yu, 2008).

Figure-2 shows schematic block diagram of automated selection of image enhancement algorithm. As seen in Figure-2, this technique implements the following methods: inverse filtering, Wiener filtering, smoothing based on least-square fitting, Lucy-Richardson iterative nonlinear image restoration algorithm and blind deconvolution.

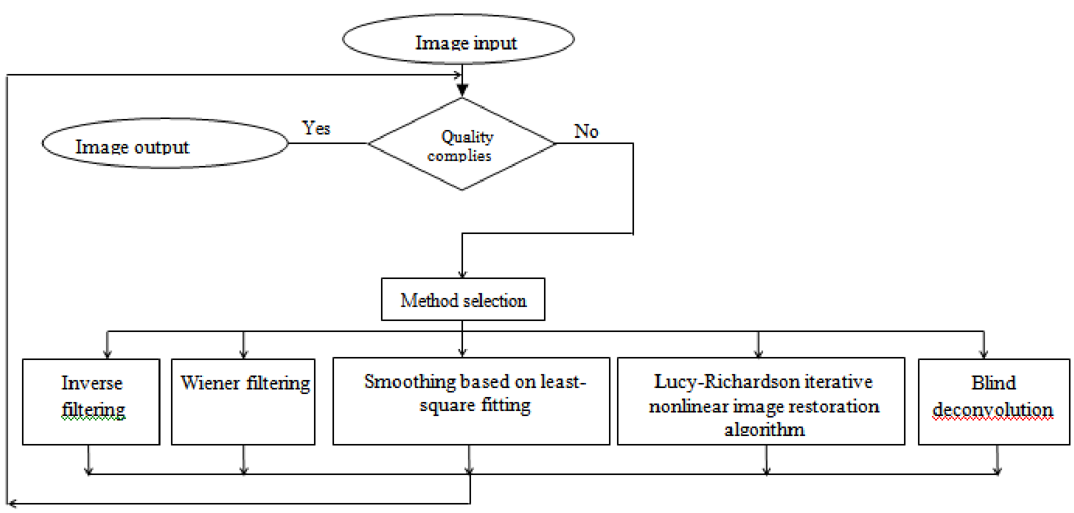

Figure-2. Schematic block diagram of automated selection of image enhancement algorithm.

It may be noted that in recent times the blind deconvolution methods have become increasingly popular.

To the subjective viewpoint of the authors, image processing by Lucy-Richardson method has proved to be the most preferred. Figure-3 (Kiryanov, 2010).

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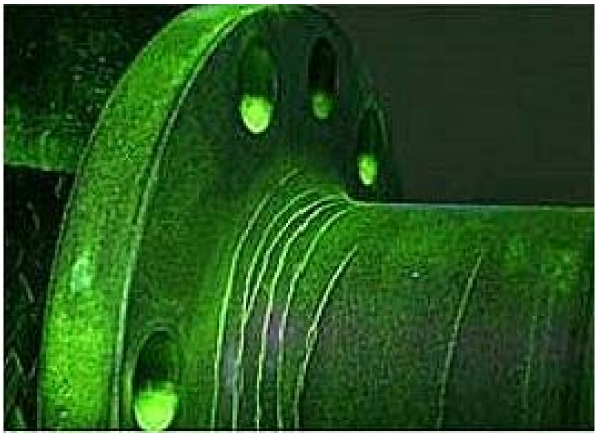

Figure-3. The result of initial image processing by the Lucy-Richardson method.

Object Edge Detection in the Image

The task of object edge detection occurs rather often in digital image processing, for example, during defect edge detection. Specifically many image recognition methods are based on edge detection. This is connected with the fact that edge analysis is low sensitive to total illumination level. Edge detection intensifies contrast (gradient). According to the definition, contrast is the difference in brightness between objects or regions. In view of the fact that the contrast between objects and background occurs on the edges, this circumstance forms the basis of object edge detection in the image. It can be noted that human vision detects object edges similarly.

There is a fair amount of mathematical methods for edge detection. However all these methods are based on the differentiation procedure (in the continuous case) or substitution with finite differences in the discrete case? In addition, practically all edge detection methods may be divided into two categories: based on search for maximum values and based on search for zero crossing. The maximum-search-based methods detect edges by calculating the edge-strength, such as gradient magnitude, and then by looking for local maximums of the edge-strength using estimated boundary direction, as a rule, perpendicular to the gradient vector. Since image intensity is defined by the function of two variables $f(x,y)$, its gradient shows the direction of maximum intensity variation and is calculated as follows:

$$\nabla f = \left[\frac{\partial f(x,y)}{\partial x}, \frac{\partial f(x,y)}{\partial y}\right] \quad (1)$$

Gradient direction (angle) is calculated by formula:

$$\theta(x,y) = \arctan\left(\frac{\dfrac{\partial f(x,y)}{\partial y}}{\dfrac{\partial f(x,y)}{\partial x}}\right) = \arctan\left(\frac{\nabla f_y}{\nabla f_x}\right) \quad (2)$$

Edge-strength is given by the gradient length:

$$\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \quad (3)$$

The zero search-based methods look for abscissa axis crossings of the second derivative expression, usually, the Laplacian zeroes or non-linear differential expression zeroes, as it will be described below. Image smoothing, generally by Gaussian filter, is practically always used as a pre- processing step for edge detection.

Edge detection methods differ in the applied smoothing filters and techniques for edge-strength calculation. Though many edge detection methods are based on image gradient computation, they differ in the types of filters used to calculate gradients in x and y direction.

The defined problem may be solved with the help of contour extraction algorithms. Sobel, Prewitt and Roberts methods are applied most frequently. These methods use the basic property of brightness - its discontinuity. The most common algorithm for discontinuity finding consists of using a sliding mask which is also called a filter, a window, a kernel or a template. In fact a mask is a square matrix that is put into correspondence with the given set of pixels in the initial image. The matrix element is called a coefficient. Mathematical transformations for the local areas of the image with the use of this matrix are called spatial filtering, or simply filtering.

The spatial filtering process is based on linear moving the filter mask from point to point in the image – filter response in each point (x,y) is computed using a predefined relationship. In case of linear spatial filtering the response is given by a sum of products of filter coefficients and the corresponding image pixels in the areas spanned by the filter mask.

Discrete analogues of first- and second-order derivatives are used to detect jumps in brightness values.

Morphological Image Processing

After obtaining image of quality satisfying the researcher, morphological processing of this image is carried out. Such processing is required to extract certain components of the image, in other words, to identify defects, that is to solve the defined problem. Then the process of solving the defined problem can be presented as

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a scheme shown in Figure-4. And the step of "Morphological image processing" is presented as a scheme shown in Figure-5. Let us demonstrate the operation of this step continuing from the image in Figure-4.

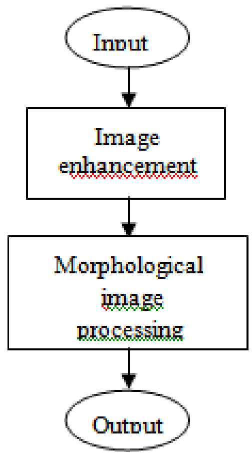

Figure-4. Solution pattern.

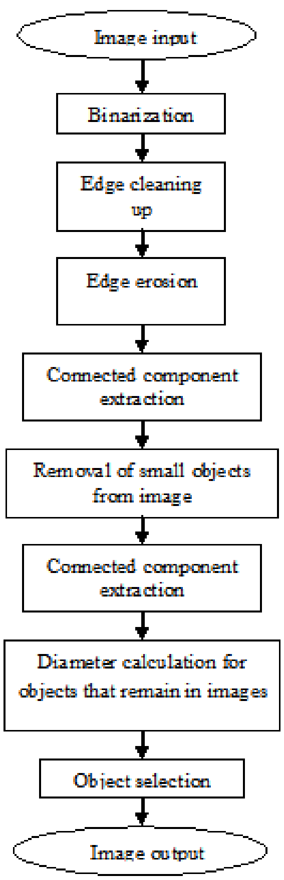

Figure-5. Schematic block diagram of "morphological image processing" stage.

As a preliminary, it is necessary to perform image binarization, i.e. image pixel values will equal to 1 or 0. Figure-6. By means of morphological reconstruction we can clean up the image from the objects being in contact with the boundary. Figure-7. Further we shall thin (erode) object boundaries in the image. The result is shown in Figure-8.

Figure-6. Binarization result of Figure-4.

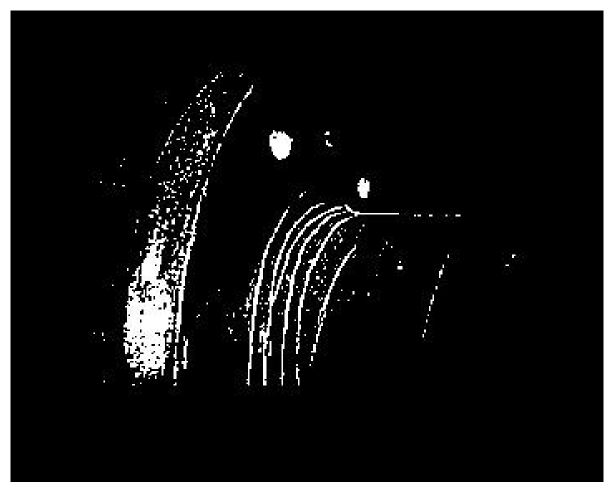

Figure-7. Morphological reconstruction of Figure-6.

After that we extract connected components in the obtained image. There are 56 connected components for Figure-8. This means that 56 objects are present in the image. With the help of morphological closing operation and using connected components we remove small objects from the image. The result is shown in Figure-9. Connected components are determined for the obtained image. There are 7 of them. We calculate diameters for 7 objects using these data.

ARPN Journal of Engineering and Applied Sciences

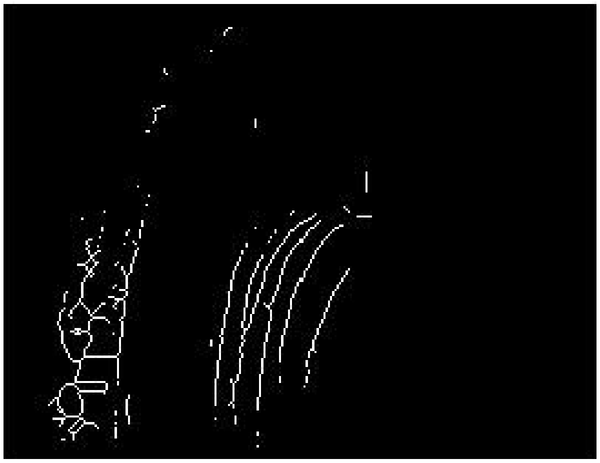

Figure-8. Thinning of Figure 6 boundaries.

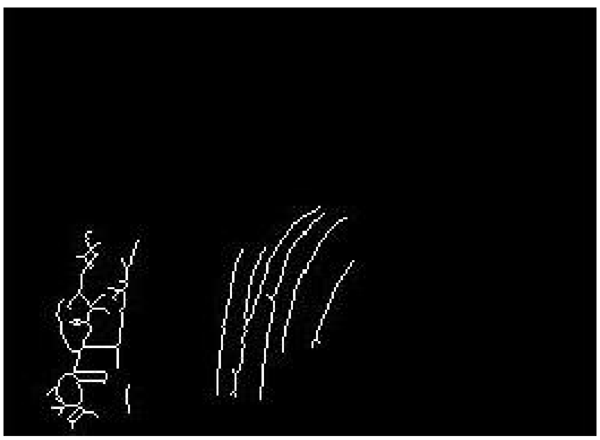

Figure-9. The result of morphological closing Operation of Figure-8.

The object with the least diameter can be removed.

Then, having a look at Figure-8 and Figure-6, it can be concluded that two left objects in Figure-9 are not a result of welding operation (flange hole and edge). Therefore they are disregarded in decision-making as to the presence of defects in the flange.

CONCLUSIONS

As a result of the presented algorithm operation, the specialist shall obtain the information based on which a conclusion can be made on the presence of defects in the investigated part. The discussed example demonstrates that the lines (objects on the right) are continuous and have no sharp shift in direction. Therefore it may be concluded about the absence of discontinuities (defects) in the part.

In addition, it can be said that binary images may be inverted at the researcher's option.

The toolkits applied in image processing, may be distinctly different (Visilter, 2007). The authors used MATLAB in the course of the discussed investigations (Gonzalez, 2009).

Finally we have to note that this procedure is open. That is various methods may (and even need to) be added to it for operation with digital images, for example, to reconstruct blurred images. In this case it is necessary to solve Fredholm integral equation of the first kind, solution of which is quite a difficult task. That is why involvement of various methods, for example, Tikhonov regularization, is a necessary condition.

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