Detection of Structural Faults in Cylindrical Glass Bottles, Applying Mathematical Morphology and Wavelets

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Abstract. In this paper we present a detailed report of a set of tests realized with the detection of structural faults in cylindrical glass bottles and with engraving in the body of them, we used two aspects important pertains to mathematical morphology: dilation and erosion. Principally, we used the dilation and erosion operations to eliminate the engraving in the glass bottles. After that, we employed a Daubichies wavelet level one and five. It helps us to find the location of the fault in the glass bottles. We present a total of seven steps to reach up our objective. The results showed in this paper show us that the methodology employed can be used satisfactorily in other similar industrial process.

Key Words: Structural faults, Cylindrical glass bottles, structural element, Mathematical Morphology and Daubichies Wavelets.

1. Introduction

The term "monochromatic image" or simply image, it refers to a function of intensity in two dimensional, and it could be represented as $f(x,y)$, where x and y indicate the spatial coordinates and the value of $f(x,y)$, in any point (x,y) it is proportional to the luminosity (or grey level) of the image.

A digital image is really a function $f(x,y)$ that has been digitalized as spatial coordinates as luminosity. A digital image can be considered as a matrix where rows and columns, that identify a point (a place in the two-dimensional space) in the image and the corresponding value of element of matrix, identifies the grey level in that point. The elements of these digital arrangements are called elements of image or pixels.

In treatment of images, three stages can be distinguished:

1. Image Acquisition.
2. Image Processing.
3. Presentation to the observer.

Image acquisition is realized by some transducer or a set of transducers that by means of the manipulation of the light that is reflected by the bodies, is achieved to

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form a representation of the object giving place to the image. It is important to know that during the stage of acquisition, the transducers add noise to the image. Besides the noise, the transducers possess a limited resolution. As example of transducers we can mention the following: the human eye, sensors video camera, computerized axial tomography in others.

Digital image processing consists in try to reduce the major quantity of noise that it joins during the acquisition, also to improve the characteristics of the image mentioned above. At the same time to try to find the contour definition, color, brightness, etc.; it makes it using principally mathematical tools. In this stage there are also a set of techniques relational with the codification that it permits storage or transmits the image.

Presentation to the observer consists in a method used to expose the image to the eyes of the people which can be by printed or electronic means such as the television, the monitor or some another way. For image presentation must be considered certain aspects of human perception as well as speeds of the devices employed.

A brief study on the functionality of the visual human system (Human Visual System, HVS), permit us to have an understanding better the form in which we perceive the images and with it, to be able to exploit these characteristics in digital image treatment. It is possible to try to see the human eye as a linear and invariant system in the time. For that are necessary to have present two concepts:

1. Impulse response, this function describes the behavior system in time domain; in our case our eyes represent the visual system. Once obtained the impulse response, we can use convolution function employing another function $\phi(x,y)$, with the aim to observe and to know the response system with respect to $\phi(x,y)$.

2. Transfer function; this function describes to the system in frequency domain. The Fourier transform is the representation of the impulse response in frequency domain.

2. Mathematical Morphology

The basic description of the Mathematical Morphology rests on "theory of sets" which was developed by Minkowsky [Minkowsky, 1897], [Minkowsky, 1901] and Hadwiger [Hadwiger, 1957], [Hadwiger, 1959]. Matheron and Serra continued with that research and their works given origin to the Mathematical Morphology as we known today. Most of this theory has been developed in the *Centre of Morphologie Mathématique* (CMM) of *lÈcole des Mine of Paris*.

Nowadays, the area and scope of the morphologic processing has been as wide as image processing. We can find applications such as the segmentation, restoration, detection of edges in another. The works [Matheron, 1967], [Matheron, 1975], [Serra, 1981] and [Serra, 1988], contains into them, a set of great details of the basic concepts adopted into mathematical morphology. They established the following properties and aspects:

Transformations morphologic. Any morphologic operation is the result of one or more operations of sets (union, intersection, complementation ...), where intervene two sets *X*, *Y*, both subsets of a joint space *Z*. Of both subsets, *Y* receives the name of structural element, and *X* represents the image to be treated on the space *Z*.

Invariability to translation. $\psi(X_p) = (\psi(X))_p$ where *p* it is the factor of adjournment of the set.

Compatibility with the centric stretching. We suppose that *X* is a centric stretching of a point set *X*, therefore, the coordinates (this is every point in the set), are multiplied for some positive constant. This is equivalent to change scale with regard to some origin. If Ψ *it* does not depend on the scale, it is an invariant at the rate of scale:

$$\psi(\lambda X) = \lambda\psi(x) \tag{1}$$

Local Knowledge. The morphologic transformation Ψ possesses the principle of local knowledge if for any point set *M*, subset of the authority *N*; the transformation of the set *X* restricted to the authority of *M*, and later restricted to the authority *N*, is equivalent to apply the transformation $\Psi(X)$ and applying the result in *M*:

$$\psi(X \cap N) \cap M = \psi(X) \cap M \tag{2}$$

Continuity. In summarized form, this principle affirms that the morphologic transformation Ψ does not exhibit any abrupt change. The notion of continuity depends on the notion of vicinity, that is to say, on the topology.

Elementary Morphologic Transformations. The morphologic transformation is the extraction of geometric structures in the sets on which it occurs, by means of the utilization of another set of known form element called structuring. The size and the form of this element are chosen to priori. Basic examples of structural element are the following ones:

Fig. 1 Structural Elements

Erosion and Dilation. They are both morphologic basic operations, from which they all are defined the others. *A* and *B* are sets of Z^2, the *erosion* of *A* with regard to *B* is defined:

$$A\Theta B = \{x \ (B)_x \, | b \subseteq A\} \tag{3}$$

is to say, is formed by the point set '*x*' that do that *B*, moved according to the vector '*x*', is completely contained inside the set *A*.

Another possible definition is the intersection of all the adjournments of *A* with regard to a vector belonging to the set $\hat{B}$:

$$A \ominus B = \cap \{(A)_b | b \in \hat{B}\} \text{ (Sternberg's definition)} \tag{4}$$

If the set B is symmetrical with regard to the origin, $\hat{B} = B$ and, then, Sternberg's definition coincides with *Minkowski's subtraction*.

The *dilation* of A with regard to B is defined:

$$A \oplus B = \{x \mid (B)_x \cap A \neq \phi\} \tag{5}$$

it means, that $A \oplus B$ is constituted by all the points 'x' such that on having reflected B and then to displease with regard to 'x', the resultant set to overlap with A, at least in a point.

As in the erosion, another alternative definition exists for the dilation:

$$A \oplus B = \cup \{(A)_b | b \in \hat{B}\} \text{ (Minkowski's sum)} \tag{6}$$

that represents the union of all the adjournments of A with regard to the points that they form B. The set B is named *structural element* and every point of the sets is a *pixel* of the image. In binary images, the pixels have only two possible values: 1 or 0.

An example of the erosion is the elimination of pixels that, for reasons of threshold (in the segmentation of the image) or for noise, are give up to 1 when they should be to 0. The election of the pixels to erase depends on the form of the structural element. The result of the operation is the reduction of the size of the original image. It is what it is possible to verify in the following example, where a triangle is eroded using a disc as element structuring.

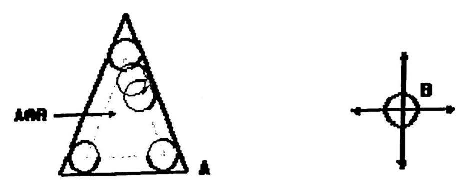

Fig. 2 Erosion on a Triangle

In dilation, the image expands with regard to the original, which implies the putting to 1 of pixels that originally were in 0. As example, it shows the dilation of a triangle by means of a disc.

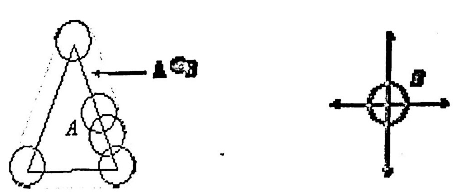

Fig. 3. Dilation on a Triangle

The simplest erosion (*classic erosion*) is that one in which a determinate amount of pixels are eliminated. This supposes eliminating a line of pixels in the edge of the objects of the image. In analogous form, the mechanics of the *classic dilation* is to add to an object (to establish 1) a set of pixels. That is to say, a line of pixels will expand about the periphery of the object of the original image.

Two of the properties of the erosion and expansion are:

1. Both are monotonously increasing operations with regard to structural element given.

$$A_1 \subseteq A_2 \Rightarrow A_1 \ominus B \subseteq A_2 \ominus B \qquad A_1 \subseteq A_2 \Rightarrow A_1 \oplus B \subseteq A_2 \oplus B \quad (7)$$

As the dilation it is commutative, also it will be monotonously increasing with regard to an image of entry. For the erosion it is not fulfilled.

$$B_1 \subseteq B_2 \Rightarrow A \oplus B_1 \subseteq A \oplus B_2 \qquad B_1 \subseteq B_2 \Rightarrow A \ominus B_1 \subseteq A \ominus B_2 \quad (8)$$

We can conclude that it is the size and form of the structural element what determines grows up/reduction of the image.

2. Erosion and dilation are dual operations.

$$A \ominus B - [\bar{A} \oplus \bar{B}] \qquad A \ominus B - [\bar{A} \ominus \bar{B}] \quad (9)$$

According to this, to erode an image it is equivalent to the dilation of its complement, that is to say, the erosion of the object that is in first plane of the image is equivalent to the dilation of the bottom of the same one. A similar reasoning can be applied to the dilation: it expands the image in the first plane and shrinks its bottom.

3. Wavelet Transforms

Wavelet transforms are the result of a great number of researches and constitutes a skill of recent analysis. Initially a geophysical Frenchman called Jean Morlet [Strang, 1989] [Torrence and Compo, 1998] was investigating a method to shape the spread of the sound across the terrestrial bark.

As an alternative to the Fourier transform, Morlet used a system based on a prototype function, which fulfilling certain mathematical requirements and by means of two processes called expansion or climbing and translation. The simplicity and elegance of this new mathematical tool was recognized by a French mathematician called Yves Meyer [Heil and Walnut. 1989] [Strang, 1989] [Devore and Luvier, 1991] who discovered that the wavelets are formed by orthonormals bases of spaces occupied by functions which square is integral. In this moment a small explosion of activity happened in this area, engineers and researchers began to use wavelet transforms for applications in fields such as: astronomy, acoustics, nuclear engineering, images compression, speech recognition, neurophysiology, optics, magnetic resonance, radar, etc.

The wavelet term can be interpreted as a "small wave" or function reachable in the time, which seen from a perspective of the signal analysis or processing can be considered as a mathematical tool for the signal representation and segmentation, analysis time-frequency, and easy implementation of algorithms. The proper characteristics of the wavelet transform grant to us the possibility of representing signals in different levels of resolution.

Daubichies Wavelet. The last great volley of the revolution of the wavelets went off in 1987, when Ingrid Daubechies, while he was visiting the Courant Institute of the University of New York, and later, during his works in the laboratories AT&T, discovered a completely new class of wavelets, that not only were orthogonal (as those of Meyer) but also they could be implemented by means of simple ideas of filtered, in fact, by means of short digital filters. The new wavelets were almost so simple to programmer and to use as Haar's wavelets, but they were soft, without the jumps of Haar's wavelets. The signal processors were having now a tool of dream: a way of separating into its elements digital information in contributions of diverse scales.

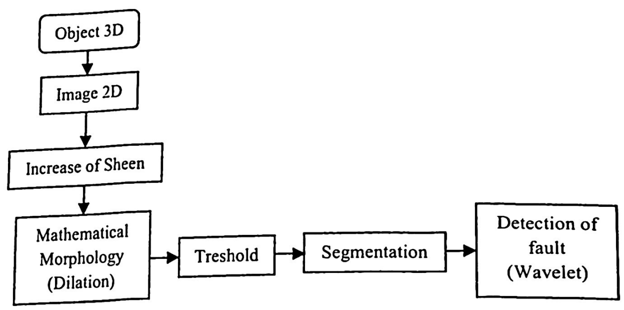

Fig. 4. Digital Image Processing

4. Experiments and Results

Figure 4 shows the evaluation of the glass bottles using digital image processing.

Primarily, we decided to have a group of glass bottles with structural faults and another group that not contains them. The glass bottles were different.

Secondly, we proceeded to realize the image acquisition task with a digital camera; we placed the camera in a belt conveyor abreast to our glass bottle with a white lighting. We obtained 10 successful images of glass bottles and approximately 30 glass bottles with faults. Figure 5 shows the images that were considered for our experiment.

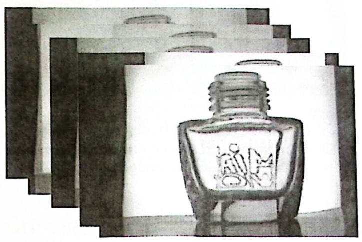

Figure 5. Images without faults

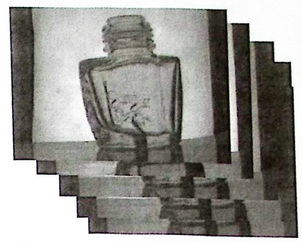

Figure 6. Images with faults

Thirdly, we applied an increase of brightness to try to eliminate the details smallest of the engraving and power, to leave the image in fewer values in scale of gray to facilitate the applications of the mathematical morphology. Figure 7 shows the results obtained.

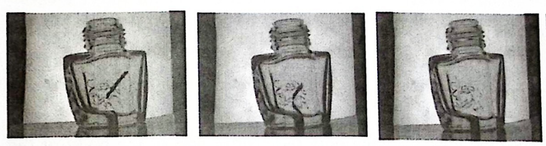

Figure 7. Original images with Faults.

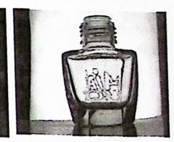

Figure 8. Original images withoutFaults.

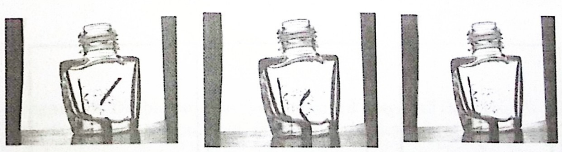

Figure 9. Images of glass bottles with faults without faults and highest brightness.

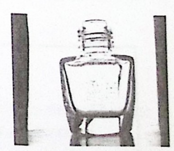

Figure 10. Images of glass bottles and highest brightness.

Fourthly, mathematical morphology was applied to the image, we employed erosion and we obtained successful results. When we applied dilation we obtained the elimination of the engraving for which we were using different types of structural elements from 3X3 up 11X11, the best results were obtained when we used a circular structural element in order 5X5.

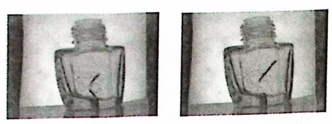

Figure 11. Mathematical Morphology (Dilation with a structural element circular in order 5X5) applied to images with faults

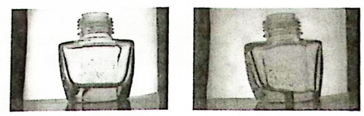

Figure 12. Mathematical Morphology (Dilation with structural element circular in order 5X5) applied to images with faults

Fifthly, a threshold was selected to reach up a better resolution of the faults. The thresholds that we used were of 25, 50, 75, 100, 125, 150, 175 and 200, we selected the threshold of 150 because it was gave us the better results.

Figure 13. Image Threshold of glass bottles with faults

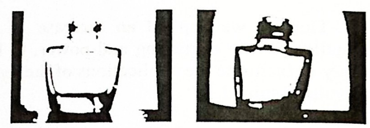

Figure 14. Image Threshold glass bottles without faults

Sixthly, we segmented the image leaving only the central part of the body of the glass bottle and we observed that fault in the bottles remained inside this segmented area. Then for means of these results, we managed differencing between glass bottles with faults and without them.

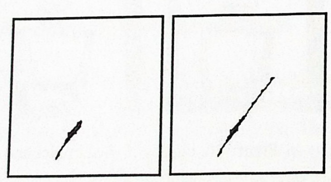

Figure 15. Image segmentation of glass bottles with faults.

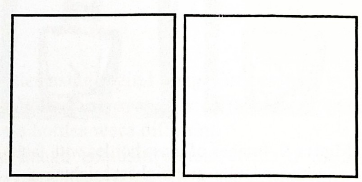

Figure 16. Image segmentation of glass bottles without faults.

Finally, we applied two Daubichies wavelets (type 1 and 5) then we were obtaining the results where the faults were located into image. If the fault appeared it locked as tape-worm otherwise we only appreciated a flat image.

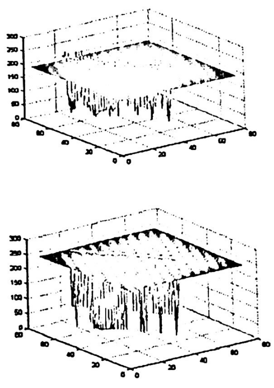

Figure 17. Up Daubichies Wavelet 1 and down Daubichies Wavelet 5 applied on a glass bottle with fault.

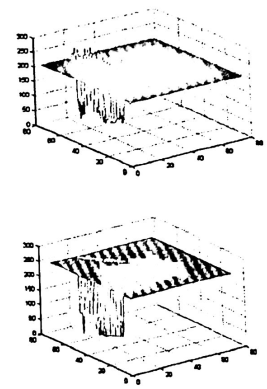

Figura 18. Up Daubichies Wavelet 1 and down Daubichies Wavelet 5 applied on a glass bottle with other fault.

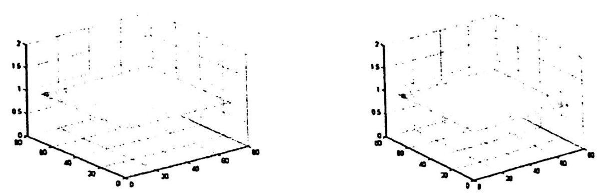

Figure 19. Daubichies Wavelet 1 in the left image and Daubichies Wavelet 5 in the right image of glass bottles without fault, for any glass bottles without fault the results are the same.

We obtained a classification of 30 bad glass bottles and 10 good glass bottles. Consider that the bad glass bottles were detected successful, but only one was not detected satisfactorily. And on the other hand the efficiency in good glass bottles was of 100%, it is to say that do not detect fault. In case of the glass bottles with fault that the experiment did not detect, it was because inside the base of the glass bottles it had problems and it made that the classification was difficult.

5. Conclusions and Future Works

We obtained good results when we worked with 40 glass bottles which 30 had errors and the others 10 were in perfect conditions, only one glass bottles can not be recognized using the methodology mentioned in this paper. Other reason because the faults were not detected adequately was because the fault was hidden in the bottle base. After results obtained we can say that the efficiency of our program developed in Matlab for the detection of structural faults in cylindrical glass bottles and with engraving, has been adequate.

As future works we propose that our set of samples must to be extended, we consider that is necessary to choose the type of classifier that permits us to find another alternative for the classification task. This classifier could be implemented with Artificial Neural Networks. We need to develop software in Builder C++ with every tools what we have used in Matlab programming. And, we are going to implement these algorithms in FPGA of Altera Company as soon as possible and it will be using images acquired from a camera connected to the development kit.

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