Bottle inspector based on machine vision

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ABSTRACT

A machine vision system for fault detection in PET bottles is presented. The bottle inspector is divided in three modules for image acquisition of bottle finish, bottle wall and bottle bottom. The captured images are corrected by adaptive gamma correction. An algorithm based in the frequency filtering of n images for defect detection of bottle wall and bottle finish is proposed. We obtain a correct rate classification of 85.5 % in bottle finish, 80.64 % in bottle wall and 95.0 % in bottle bottom.

Keywords: bottle inspection, machine vision, quality control

1. INTRODUCTION

Machine vision inspection system has been successfully applied in many industries such as circuit production,[1] the fruit,[2] textile,[3] iron mine[4] and quality inspection.[5] It brings several advantages for the quality control of production, such as safety, reliability, repeatability, and accuracy. During the production of bottles, there are many kinds of defects. So the quality control is an essential part of any bottle production system.[6] Bottles are inspected for manufacturing faults such as damage, cracks or shape deformation in the bottle finish or bottle wall and dirt particles in the bottle bottom. Because bottle inspection by human inspectors results in low speed and efficiency. The bottle inspector is one of the typical applications of machine vision and digital image processing technology in industry production.[7] Several configurations of optical systems are used to capture the image of the moving bottles. Some of them include only three cameras[7] and others twelve.[8] If the number of cameras increases the bottle inspection without rotation is done and also images with full view of bottles are taken. The defects in bottle finish are considered as critical defects by bottle manufactures. Few inspection algorithms are implemented for this kind of defects, Canivet[9] et al. detects the finish cracks through the variation of the gray level on two arcs of ellipse into the image. Shafait[6] et al. inspects the bottle bottom. They used the generalized Hough transform to detect different shape of bottles. The decision for a defect is based on intensity variations on the bottle image. Duan[7] et al. inspects the bottle wall and bottom using the local statistical characteristics. In the second section we present a machine vision system used to acquired the bottle images. Section 3 gives an overview of the image processing method based in frequency analysis for defect detection in the bottles. The correct rate classification (CRC) results are showed in section 4 and conclusions are given in the last section.

2. BOTTLE INSPECTOR

2.1 Image acquisition system

Digital images of a bottle are acquired for defects detection in the bottle finish, bottle wall and bottle bottom. The shape of a defect is chosen from a base of defects given in the Table 1.

Table 1. Kind of defects

bottle finish	bottle wall	Bottom of the bottle
crackles	crackles	dirt particles
deformation	stains	sticky objects

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The inspection is divided in three modules, each one is equipped with CCD cameras, zoom lenses and illumination systems based in LED lights. The acquisition system uses a scan CCD camera, which is able to obtain a whole frame image at one shuttle in 1/16 second. The gray level image resolution is 1432×1050. The zoom lens focal length is $37 - 75$ mm and the green LED light have a field of view of 7.6 a 22.8 cm and also a plate LED light source is used.

2.1.1 Bottle finish inspection

In the bottle production, the detection of defects on the finish is one of the most important and difficult steps in quality control.[9] The defects, which are yielded by temperature variation, looks like cracks in the bottle. A CCD camera is used to capture the bottle finish. The optical system detects vertical cracks in upper portion of a bottle. But the finish defect reacts like a mirror when it is lighted by a beam. So an appropriate design of illumination is beneficial to simplify the image processing. The illumination setup used for the image acquisition is shown in Figure 1.[9]

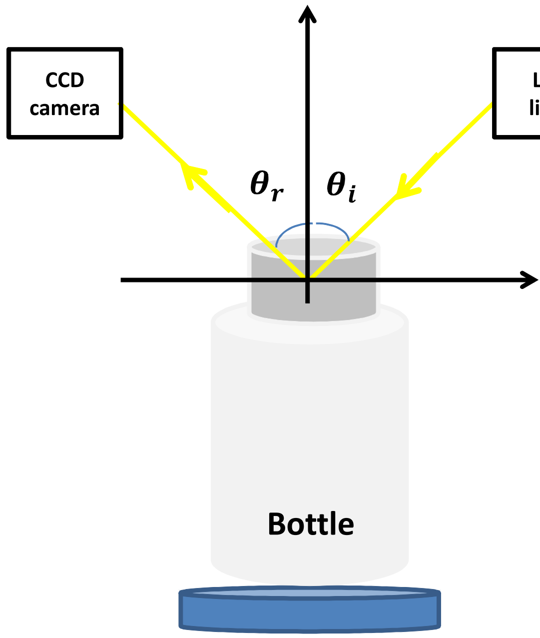


Figure 1. **Principe of detection by reflection** $\theta_i = \theta_r$

The CCD camera can observe their image in a large space around the finish, which can improve inspection efficiency. Figure 2 shows images of 300×300 pixels. The captured images (a) and (b) are corrected by adaptive gamma correction.

For scanning whole bottle finish without rotation, two images are captured from perpendicular angles. This system provides two views of the same item. Also two LED light sources are used. The proposed basic structure of the bottle finish inspector is shown in Figure 3.

2.1.2 Bottle wall inspection

For inspection of bottle wall a transmission-illumination system is used. This optical setup allows that cracks and stains can be displayed in the image. Figure 4 shows the position of the camera and light source that photos the bottle wall.

In order to scanning whole bottle wall without rotation, two images are captured from perpendicular angles. Also two plane light sources are used. The basic structure of the bottle wall inspector is shown in Figure 5.

Figure 6 shows two images of the bottle wall. As we can see, cracks on the bottle are displayed in the image.

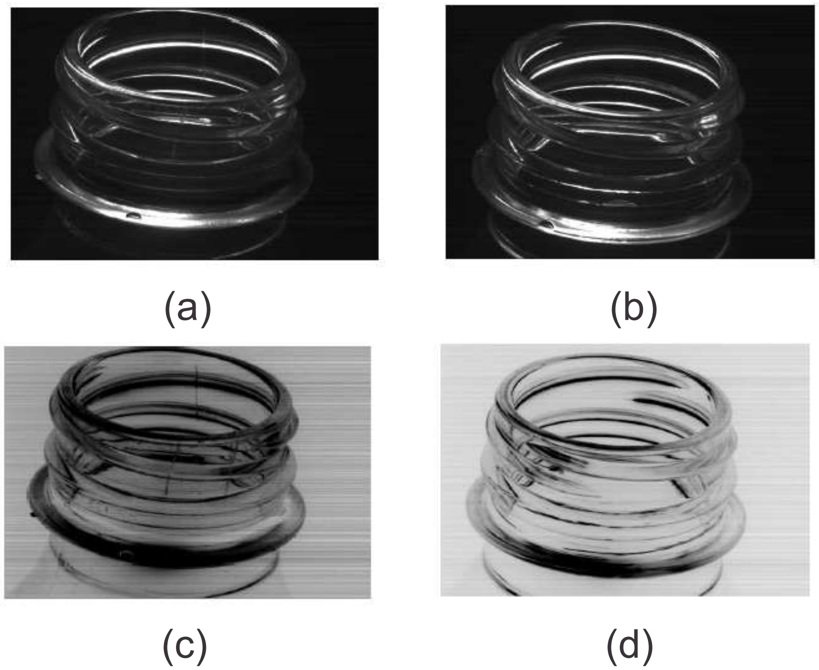


Figure 2. **Bottle finish (a) with defect and (b) without defect. (c) and (d) are an adaptive gray level correction of (a) and (b) respectively.**

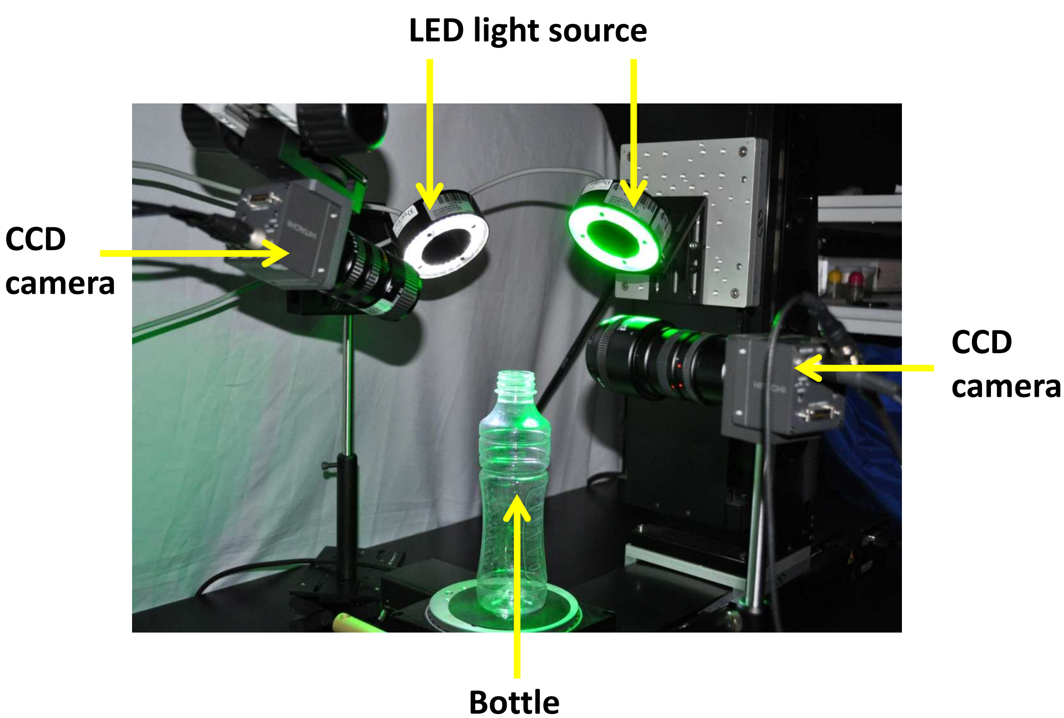


Figure 3. **Experimental setup for bottle finish inspection without rotation.**

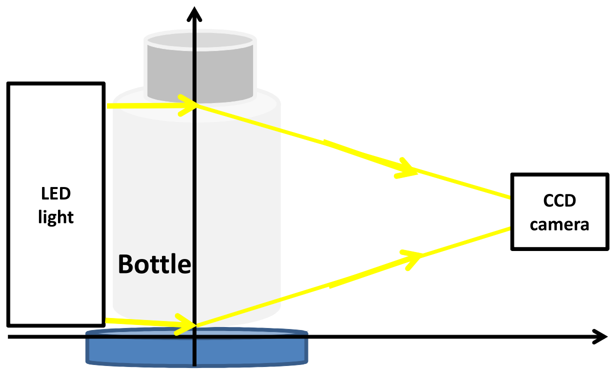


Figure 4. **Optical setup for bottle wall inspection**

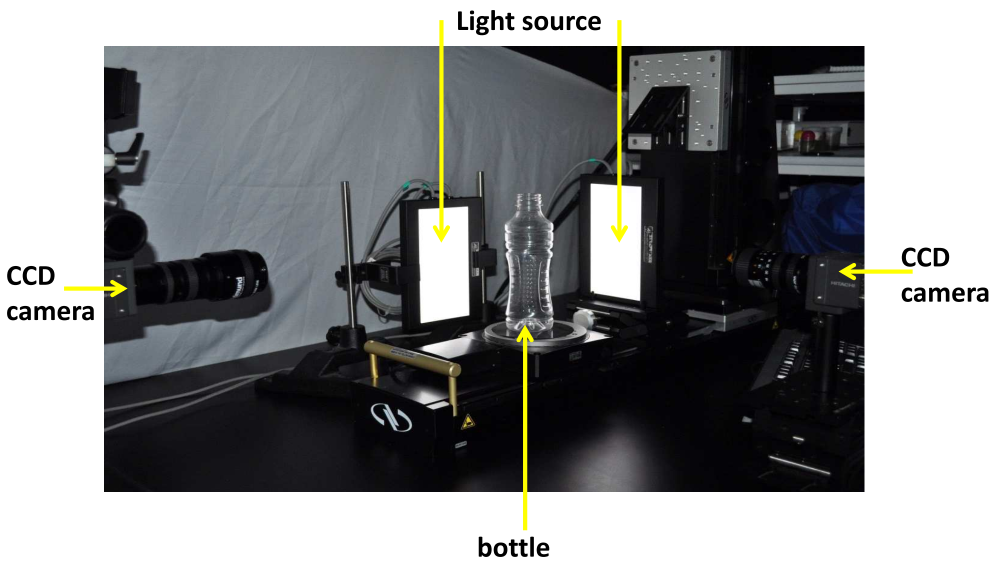


Figure 5. **Experimental setup for bottle wall inspection without rotation of the bottle but the conveyor.**

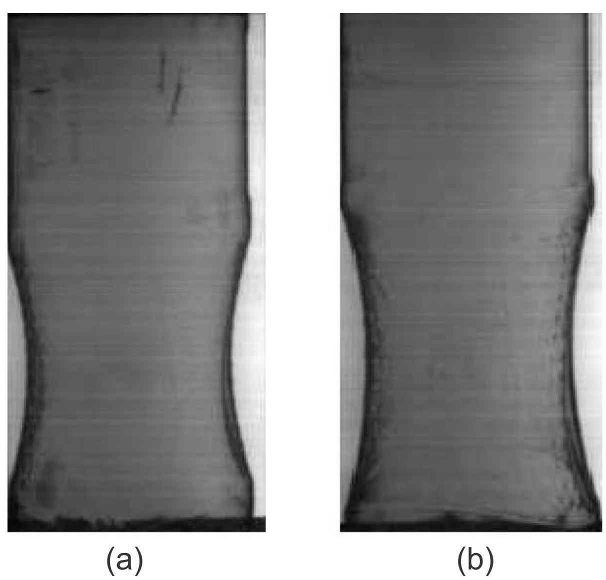
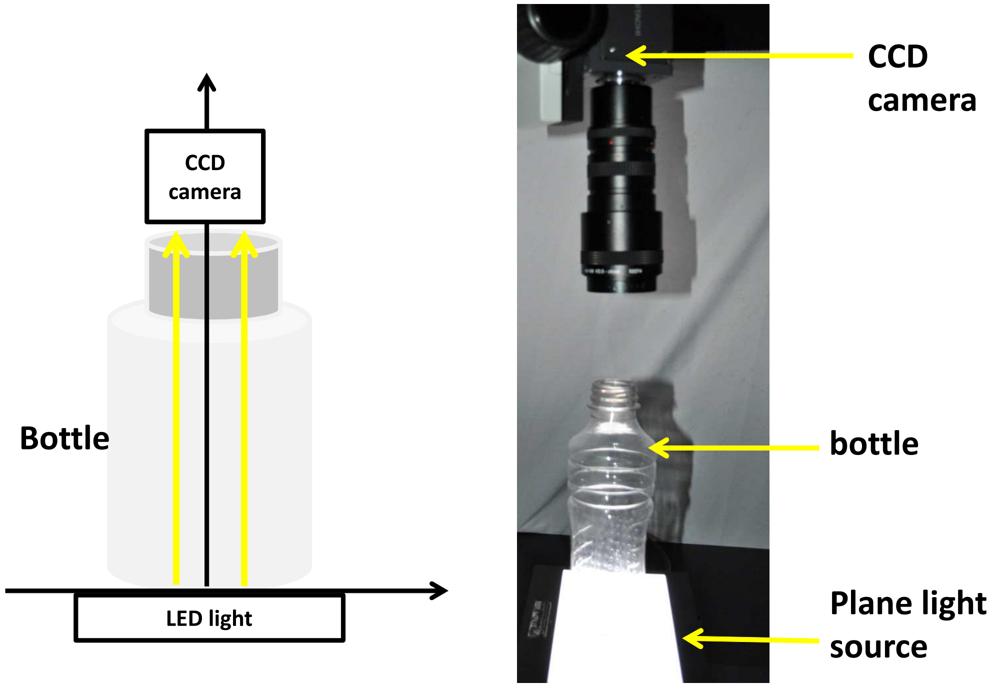


Figure 6. **Bottle wall (a) with defect and (b) without defect. In this case, the problem is the texture of the bottle.**

2.1.3 Bottle bottom inspection

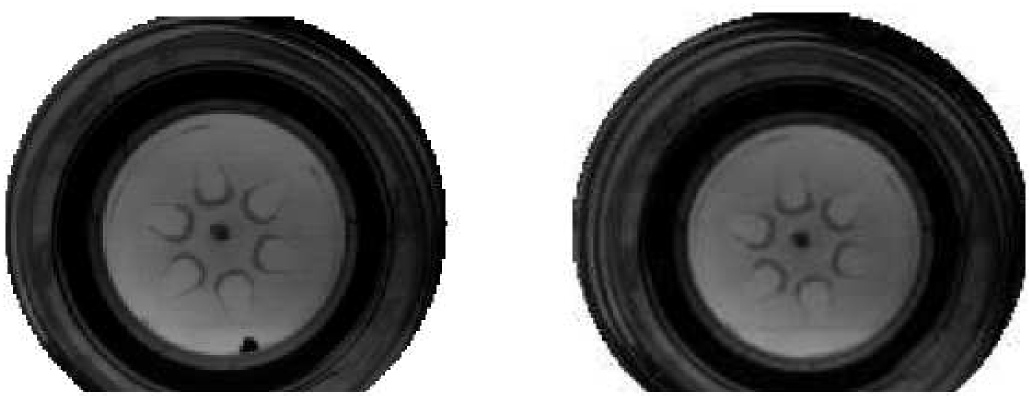
For inspection of the bottle bottom also a transmission-illumination system is used. This optical setup displays stains, breaks or dirty particles in the image. Figure 7 shows the position of the camera and light source that photos the bottle bottom.



(a) (b)

Figure 7. **Optical setup for bottle bottom inspection (a) scheme (b) implementation**

An example of bottle bottom image is given by Figure 8.



(a) **(b)**

Figure 8. **Bottle bottom (a) with defect and (b) without defect.**

A difference between a reference and input image can be used to detect a defect in the bottom of a bottle.

3. METHOD OF FAULT DETECTION

Once the position of the bottle in the camera is known and the five digital images acquired, the next step is the analysis and processing of digital images for detection of any defect. The proposed algorithms for bottle inspection are based in frequency analysis.

3.1 Discrete Fourier transform

The discrete Fourier transform of an image function $f(x, y)$ of size $M \times N$ is given by the equation,[1]

$$F(u,v) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \exp^{i2\pi[\frac{ux}{M}+\frac{vy}{N}]} . \tag{1}$$

where u and v are the frequency of the components of the transform. So $F(u, v)$ is defined in the frequency domain. Also given $F(u, v)$, we obtain $f(x, y)$ by the inverse Fourier transform with the expression,

$$f(x,y) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} F(u,v) \exp^{-i2\pi[\frac{ux}{M}+\frac{vy}{N}]} . \tag{2}$$

These equations comprise the Fourier transform pair. It is a common practice to multiply the input image function by $(-1)^{x+y}$ prior to computing the Fourier transform. With this, the origin of the Fourier transform it is located at $u = \frac{M}{2}$ and $v = \frac{N}{2}$ as follows,

$$\Im[f(x,y)(-1)^{x+y}] = F\left(u - \frac{M}{2}, v - \frac{N}{2}\right) . \tag{3}$$

Figure 9 shows an input image $f(x, y)$ and its Fourier espectra $F(u, v)$.

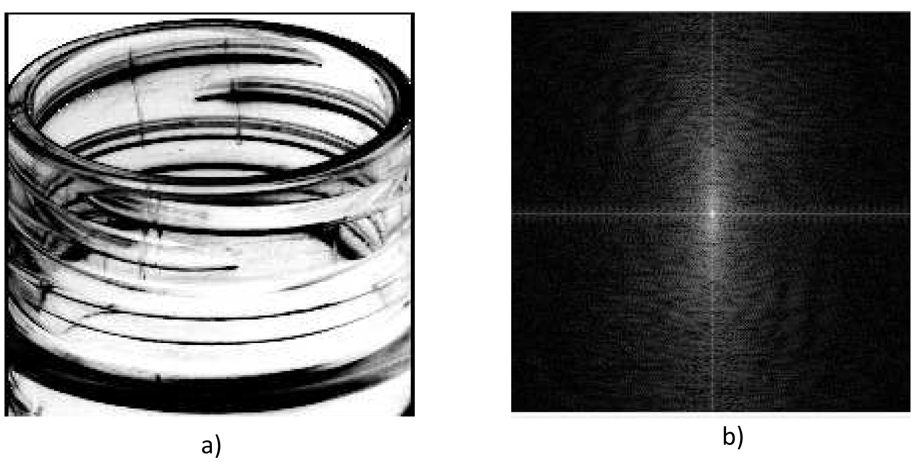


Figure 9. **a) Bottle image $f(x, y)$ and its b) Fourier spectra $F(u, v)$.**

3.2 Filtering in the frequency domain

It is known that the lowest varying frequency component ($u = v = 0$) corresponds to the average gray level of an image. As we move away from the origin of the transform, the low frequencies correspond to the slowly varying components of an image. As we move further away the higher frequencies begin to correspond to faster gray level changes in the image.

Let $H(u,v)$ denote a frequency domain filter given by the equation,[10]

$$H(u,v) = \begin{cases} 1 & \text{if } [(\frac{M}{2} - b) \leq v \leq (\frac{M}{2} + b)] \wedge [(\frac{N}{2} + a \leq u) \vee (\frac{N}{2} - a \geq u)] \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

Figure 10 shows the filter used for defect detection.

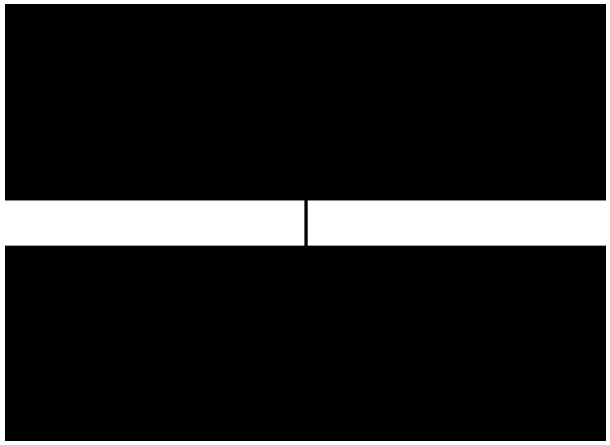


Figure 10. **Filter transfer function $H(u,v)$. It suppresses the low frequencies and high frequencies related with horizontal direction by means a and b parameters.**

Let $F(u,v)$ denote the Fourier transform of an input image $f(x,y)$ and $H(u,v)$ is a filter transfer function. The filtering in the frequency domain is given by,

$$G(u,v) = H(u,v)F(u,v), \tag{5}$$

where the multiplication of F and H is defined on an element by element basis. Then the filtered image $g(x,y)$ is obtained by taking the inverse Fourier transform of $G(u,v)$. Figure 11b shows the result of filtering 11a with the filter of Figure 10.

From this, we define an *ith* defect map $map_i^j(x,y)$ as,

$$map_i^j(x,y) = \begin{cases} 1 & \text{if } g_i(x,y) = threshold \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

for $j = 1,2,...,5$ the inspected sections per bottle and $i = 1,2,...,N$ the number of bottles.

3.3 Defect quantification

Let $map_i^j(x,y)$ denote the *ith* defect map of the *jth* section,

$$m_i^j = \sum_x \sum_y map_i^j(x,y). \tag{7}$$

The decision rule is given by,

$$Class(m,i,j) = \begin{cases} 1, & \text{if } m_i^j \geq threshold_{defect}; \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

with $threshold_{defect} = 280$ for bottle finish, $threshold_{defect} = 90$ for bottle wall and $threshold_{defect} = 300$ for bottle bottom respectively. if $Class(m,i,j) = 1$ for any j the *ith* bottle is rejected.

4. RESULTS AND DISCUSSION

For image acquisition of bottle finish, bottle wall and bottle bottom three optical systems were implemented. At the same time, three computers process the captured images. In the preprocessing step, the captured images are corrected by adaptive gray correction using gamma correction. After obtained the position of the bottle in the image, an algorithm based in frequency filtering is used for defect detection of bottle wall and bottle finish. In the case of bottle bottom inspection, it is carry on by a difference between an input image and a reference image.

Figure 11(a) shows a preprocessing image using gamma correction and convolution with a Laplacian filter. Figure 11(b) is the result of frequency filtering and (c) the binarization of the image (b) of the finish section in the bottle.

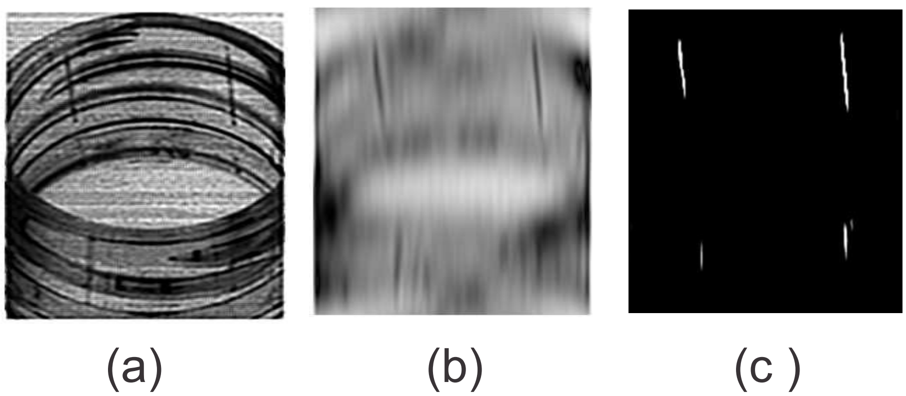


Figure 11. **(a) Preprocessing image of the bottle finish, (b) Result of filtering the image (a). (c) Defect map obtained by binarization of (b).**

Figure 12 shows a preprocessing image using gamma correction and convolution with a Laplacian filter. Figure 12(b) is the result of frequency filtering and (c) the binarization of the image (b) of the wall section in the bottle.

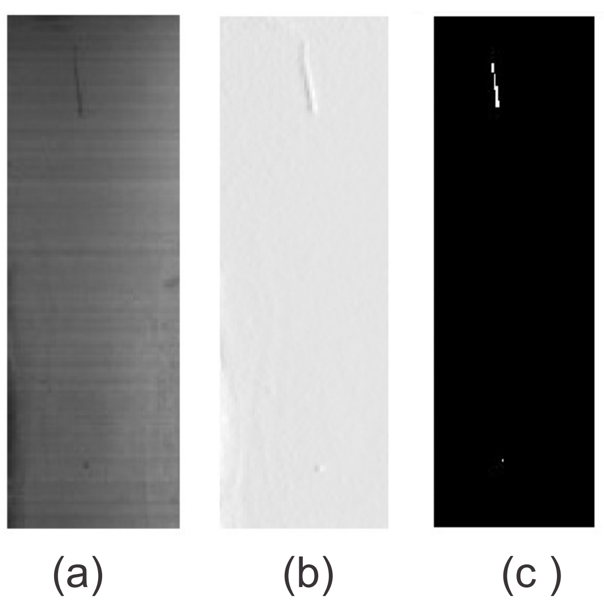


Figure 12. **(a) Preprocessing image of the bottle wall, (b) Result of filtering the image (a). (c) Defect map obtained by binarization of (b).**

Figure 13 show the difference between the input image and the reference one.

Figure 13. **(c) Defect map obtained by binarization of the diference of (a) and (b) in Figure 8.**

The inspection results will be transferred to the ejector who reject the bad bottles. Table 2 shows the laboratory results of bottle classification in two classes.

Table 2. Test Results

	No. of inspected bottles	Correct classification rate
Finish	463	85.5 %
Wall	899	80.64 %
Bottom	796	95.0 %

Although the algorithm successfully detects de vertical defects in the bottle finish, the inspection had a miss detection during the binarization process because threshold selection. In the case of the bottle wall, the miss detection is due to the confusion of texture of the bottle wall and the defect. It can be seen in Figure 6. Also the binarization is the problem in defect detection on bottle bottom.

5. CONCLUSIONS

A machine vision system for fault detection in PET bottles was presented. The bottle inspector was divided in three modules for image acquisition of bottle finish, bottle wall and bottle bottom. The captured images were pre processing by means a gamma correction and convolutioned with a Laplacian filter. It makes the edges of the image are sharper. A defect detection algorithm based in the frequency filtering of n images was proposed. The filter transfer function was designed for detection of vertical cracks in the bottle finish. The CRC was 85.5%. In the case of bottle wall was 80.64 %. The miss detection is due to the confusion of texture of the bottle wall and the defect. And the highest CRC was 95.0 % in bottle bottom.

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