Adaptive Visual Inspection Method for Transparent Label Defect Detection of Curved Glass Bottle

Wei Gong
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China 250353
g1978680651@163.com

Kunbo Zhang*
Institute of Automation, Chinese Academy of Sciences
Beijing, China 100190
kunbo.zhang@ia.ac.cn

Chengwu Yang
Tianjin Academy for Intelligent Recognition Technologies
Tianjin, China 300450
yangchengwu@tj.ia.ac.cn

Mingdong Yi
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China 250353
new-raul@163.com

Jun Wu
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China 250353
Sichuan Provincial Machinery Research and Design Institute
Chengdu, China 610063
junwu0116@163.com

ABSTRACT. Automatic visual inspection of transparent materials has always been a challenging issue in industry due to complicated interference from reflection and refraction. In this paper, we present a study of machine vision system for automatic online inspection of transparent label defect on curved glass bottle. An area-array camera and a custom-made blue dome illumination device are introduced to capture high quality standstill image by eliminating reflection. To overcome the distortion issue on curved geometry shape, we have introduced the deformable template matching method for accurate location. An adaptive threshold selection strategy is proposed to effectively detect small scratch by using global and local threshold values together with Gaussian fitting algorithm. Considering the golden edge printing error, skeleton extraction and distance transformation are applied to detect the whole edge contour of Chinese characters with special font. Our visual inspection system has been deployed in a glass bottle manufacturing plant for on-line quality control. Field test result demonstrates that the detection accuracy reaches 99.5% at a speed of 60 pc/min for over 60,000 bottles.

Keywords-Machine vision; transparent label; glass bottle; defect detection; adaptive template.

I. Introduction

Since the information of ingredient and expiration date are typically printed on package label, it is necessary to ensure the printing quality of the label. If there is a defect in the label, it will directly jeopardize the impression of a product which may even cause a customer to reject purchasing. In addition, a damaged barcode on the label may affect product transportation, stocking, traceability, and management. During the process of glass bottle label printing, various reasons may result in a defect such as printing machine jam, printing material damage, and unskilled operator. The accuracy of inspection result is uncontrollable when the operator is exhausted. Currently most of the label printed on liquor bottle are hand-picked by operator via eye check. Considering the numerous defect types such as less stamping, misprinting, blurred text, overprint, wrinkle, scratch, ink splash at various scale sizes, it is impossible to avoid mistakes in manual screening [1]. To meet the demand of increasing production capability, it is a trend to use automatic quality inspection tools to replace the traditional low efficiency, uncontrollable stability and high labor cost way. With the development of electro-optical imaging and pattern recognition technology, machine vision has been considered as effective solution in automatic defect detection and quality control of product manufacturing line [2]. Compared with traditional manual inspection, automatic visual check has the advantages of non-contact, fast speed, reliable accuracy, and history traceability [3].

So far, many studies of printing defects detection on flat surface have been successful [4-6]. And automatic visual defect inspection of curved object such as glass bottles mainly focuses on the body instead of the printed label due to the challenge in imaging [7-9]. Among the few accessible label inspection examples, Wang et al. [10] achieved the detection of the printing defects on medical glass bottles by using feature-based image registration method which compares Harris corner detection operator and SIFT feature point detection operator during feature point extraction. However, this method is only able to recognize limited simple printing defects such as font unprinted, skew, printing connection, etc. Ma et al. [11] proposed a new template matching algorithm which first matches the testing image and the template image to extract region of interest (ROI), and then distinguish the foreground and background of the image by a second template matching. Even individual printing defect on liquor bottle surface was effectively detected, such a complicated algorithm did not meet real-time running requirement in plant. For industrial application, Zhu et al. [1, 12] designed and implemented a visual inspection system for liquor bottle label print defect using a line-scan camera with simple template matching method. This prototype machine can inspect opaque label defect on bottleneck location only of a constant radius cylindrical glass bottle.

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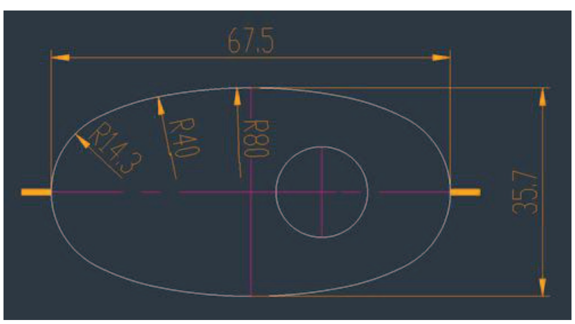
In this paper, the shape of the liquor glass bottle to detect is an elliptic cylinder which means the radius is not constant, and the printed labels are transparent and located on both sides. To achieve on-line automatic visual inspection, we have designed an imaging system using custom-made dome illumination to eliminate the effect of reflection light. A deformable template matching algorithm was used as preprocessing for accurate content localization and image differencing to detect obvious defects. In addition, a novel adaptive global and local threshold values combined method was proposed to detect small scratches and small defect on character edge contours in the label. Our visual inspection system has been deployed in a liquor glass bottle manufacturing line for real-time printing label defect detection. 8 types of challenging label defects are successfully detected with an accuracy over 99.5% after the continuous test of 60,000 bottles.

II. Image Acquisition System

For a machine vision system, the captured image determines the quality of input information for algorithm subsystem to handle. An appropriate design of image acquisition subsystem is critical important. The hardware in this study is properly selected to handle the special curved bottle geometry while maintaining high speed detection speed. In the following, we will discuss the system design of imaging components including imaging sensor, illumination module, lens, etc.

a. Front label b. Back label



c. Glass bottle geometrical size (top view)

Figure 1. Glass bottle label and size

A. Camera Selection

According to the scanning method, a camera can be generally divided into line-scan camera and area-array camera in which dedicated lighting and mechanical handling are accompanied. The line-scan type camera scanning an object with additional handling device to create relative movement which is suitable for constant radius glass bottle inspection. The detection object of this research is shown in Figure (1). It is noticed that the glass bottle is not a fixed radius cylindrical shape in which the body thickness varies. There are two transparent labels with printed characters on the front and back across both flat and curved surfaces. And there are four colors including white, black, red, and yellow on the print. In addition, the on-site production speed requires that the inspection speed should be at least 40 pieces/min, and the minimum detectable area should be as small as 0.03mm. All these conditions introduce difficulties in image capture especially the possible reflection and refraction light interferences from the glass body and transparent labels. In this case, we choose an area-array camera since a line-scan camera is not able to handle varying diameter shape. The CMOS sensor has a resolution 2448 x 2048 pixels, 2/3 " size with global shutter, 3.45μm x 3.45μm pixel size, and the frame rate up to 23.5 fps. A 12 mm lens is integrated to capture the bottle image at a distance of 180 mm and cover the inspection area of 100 x 120 mm. This monochrome camera uses gigabit ethernet to transmit data to a desktop PC equipped with i7 9700 CPU and 512G RAM.

a. Strip light source b. Blue dome light

c. Red dome light d. Green dome light

Figure 2. Comparison of captured images with different illumination setups

B. Illumination Setup

The design of the illumination subsystem directly affects the quality of the image collection and the difficulty of image processing. Appropriate illumination will not only eliminate the interference of irrelevant component, but also make the target object prominent for convenient visual information postprocessing. For a specific test specimen, the illumination setup should be designed according to the shape, material, color of the object and environmental condition. Since the uniformity and color of the printed labels on the front and back of the glass bottle are different, we can obtain the integral label images of both sides based on the principle of light transmission by removing interference.

In order to find proper illumination parameters, we have selected several types of lightings for imaging test. Figure 2 (a) shows the grayscale imaging result using a blue strip light source. It is obvious that there are excessive reflections on both curved edge of the glass bottle. If a strip light source is used, at least three cameras are required to collect a complete and clear front image together without reflection light interference which increases the cost and synchronization complexity. By the help of a blue dome light source, Figure 2 (b) shows that the label image on both curved edge areas are clear with high contrast. This is because the light emitted from the dome light source forms scattered light through the arch bowl reflection which generates uniform illumination across the curved surface. In addition, we also conducted illumination tests using different wavelength light as shown in Figure 2 (c) and (d). It is noticed that both red and green dome light blur and diminish the golden color print.

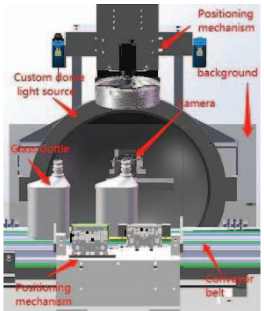


Figure 3. Schematic of image acquisition station

a. Front image b. Back image

Figure 4. Images acquisition system

C. Vision System Design

In this paper, we choose the blue dome light as our illumination source with customized geometric shape to fit the liquor bottle size and structure. The final vision inspection system includes image acquisition components and mechanical handling components as shown in Figure (3). It has two grayscale image sensors on both sides, one blue dome light source positioned on one side, dark background, conveyor belt and position mechanism to fix the bottle for standstill capture. The glass bottle is transported by a conveyor belt controlled by proximity transducer and is fixed at designated place to present for image sensor. The light source and cameras are triggered together to capture both front and back images of the glass bottle simultaneously. In this image acquisition device, the background plate is placed behind the glass bottle (Figure 3 blurs the background plate for better visual illustration). In addition, the color of the background plate in the image acquisition device on the front and rear surfaces of the glass bottle is not the same. A white background is used for front image capture since front characters are all colored. Likewise, the black background is used for back side image capture because the characters are white or printed on white area which ensures enough contrast difference in grayscale values. Figure 4 is the image collected by our proposed vision inspection system.

III. Visual Inspection Method

The general method in visual inspection for object defect is to conduct a comparison between a test target with the designed template. Before the comparison, it is necessary to use labelled images to make qualified templates. If we investigate the labels on the bottle, the printed characters can be divided into several large ROIs based on their formats as shown in Figure 5. Front area is separated into 5 regions. And back area is divided into 4 regions where the top area is separated into two parts because the left part locating on the curved edge has a different deformation shape. Our image processing algorithm workflow is shown in Figure 6. For image segmentation and location, most relative methods are well developed which is not covered in this paper. The following section focuses on three challenging issues in curved glass bottle label inspection which are template matching, small scratch detection, and golden edge defect detection.

a. Front image b. Back image

Figure 5. Label image ROI segmentation

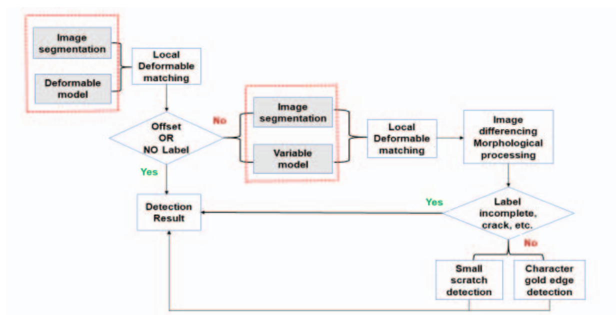


Figure 6. Visual inspection algorithm flowchart

A. Deformable Template Matching

Template matching is the process of finding the template image among testing samples by calculating the similarity of two images based on similarity measure [12]. There are three major template matching algorithms: template matching using grayscale value, template matching based on edge point, and template matching based on shape. In general, the shape-based template matching algorithm can effectively recognize and locate the image with fast processing speed which has a good potential in label defect inspection application [13]. Because our glass bottle curved surface has a various diameter in which the label print has large distortions especially on marginal area, it is difficult to use traditional shape-based template matching algorithm for accurate positioning. As shown in Figure 7, there is an obvious mismatch between the template and the testing image. The difference becomes larges as the position of the character towards the edge. Therefore, we use the local template deformation matching algorithm to realize accurate template matching. This matching algorithm can change the size of the template, and automatically deform template shape according to the object which can effectively solve the positioning problem caused by the distorted label on curved surface. As shown in Figure 8, this deformable method can achieve accurate matching even for the characters close to the edge.

During the process of deformable template matching process, we use Gaussian pyramid algorithm to search the images in the ROI to speed up the template matching. By setting a proper smoothness value, the overall matching performance is evaluated based on the effect of edges matching result. After image registration, the pixel points of the testing image have been mapped to those in the standard template. The grayscale value difference between the two images is calculated as a new differential image which is namely the defect image. As shown in Eq. (1), $T(m,n)$ is the pre-established template image, $G(m', n')$ is the testing label image of the liquor bottle, and $D(x, y)$ is the differential image.

$$D(x, y) = |\, T(m,n) - G(m', n') \,| \quad (1)$$

In this paper, the dynamic threshold algorithm is used to binarize both the template image and the testing image before differential processing of selected region. The differential result shown in Figure 9b indicates that this deformable template match algorithm is able to detect the label defect on curved surface.

Figure 7. Traditional template matching

Figure 8. Deformable template matching

a. The defect Image

b. The differential image

Figure 9. Defect detection using template matching

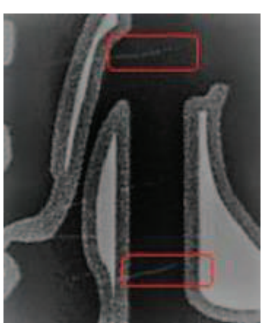


Figure 10. Scratch image

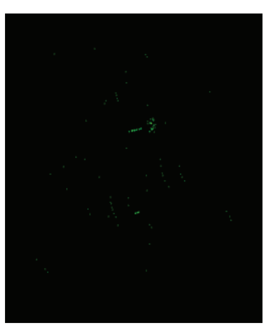


Figure 11. Traditional method

a. Adaptive threshold

b. Mean filter

c. Fixed threshold

d. Small scratch image

Figure 12. Adaptive small scratch processing

B. Adaptive Small Scratch Detection

Among the various defect types of printed labels on liquor glass bottle, small scratch is relative small in size and difficult to observe compared with large defect and missing print as shown in Figure 10. Even after differential and morphological processing, such kind of small scratches are still challenging to identify as shown in Figure 11. Therefore, an overall adaptive threshold segmentation method combined with local threshold segmentation is proposed for small scratch detection. Firstly, the ROI is extracted and segmented by adaptive threshold algorithm (Figure 12a). Then, a mean filter is applied for noise reduction (Figure 12b). Since the font color is black, a background estimation algorithm is used for image enhancement and highlight the target small scratches. After that, the image is segmented by dynamic threshold (Figure 12c). The processed image shows defect candidates, but some of these lines are not scratches. In order to avoid misidentification of small scratches, the dilation algorithm is introduced to fill the inner holes of the image and the line fitting algorithm is used to identify the line after dilation processing in the last step (Figure 12d). In our label inspection situation, most of the small scratch are linear lines.

Figure 13. Original image

Figure 14. Segmentation trial

Figure 15. Edge detection, area connection, hole filling

Figure 16. Golden edge contour

Fig 17. Skeleton extraction

Fig 18. Distance transform

C. Character Edge Contour Inspection

Another challenging issue in curved label inspection is the golden edge contour defect of the large "Lang" character with a special font. Since the outer golden contour adjoins the inner red character skeleton, it is extremely difficult to separate the outer contour and the inner content of this character using template matching method when the defect area is not large as shown in Figure 13. Therefore, we propose a novel defect area inspection algorithm to detect defect in irregular character outer contour. To separate the two regions, this method extracts the golden edge contour of the character and calculate the distance between the inner skeleton to the outer edge since the golden edge contour has a constant width. The tricky point in skeleton extraction is to get an accurate character golden outer contour. Considering the adjoining situation of the outer and inner regions, it is impossible to use them same threshold value to segment the whole character. A failure segmentation result is shown in Figure 14 since the grayscale value is not uniform due to curved shape of the glass bottle. Here we use the area filtering algorithm which filters the image processed after edge detection, area connection, and hole filling according to the adaptive threshold value in the ROI as shown in Figure 15. The golden edge contour detection result is presented in Figure 16 and Figure 17. Compare with trial test in Figure 14, it is obvious that this skeleton extraction with area filtering method can segment the inner content and our contour of the special character accurately. Finally, the distance value between the edge and the skeleton is calculate in grayscale image to determine if there is a defect in the golden edge contour area as shown in Figure 18. This method is also robust to dilation and erosion operations when necessary image processing step is required.

IV. Experimental results and analysis

Using the above methods, the printing defects on the curved glass bottle were inspected such as label offset, crack, bubble, small scratch and character edge contour defect after the machine vision system deployed in the liquor bottle manufacturing plant as shown in Figure 19. Two continuous tests are conducted to evaluate the accuracy and reliability due to the limited sample numbers in certain defect types.

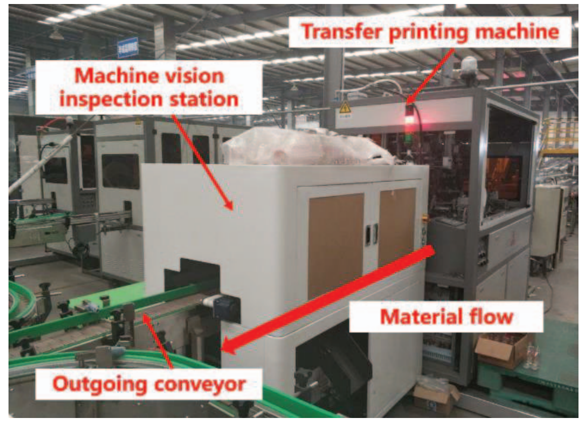


Figure 19. Machine vision inspection station deployment

In order to show the statistical testing result, we run a 20-hour on-line test for both good and bad printed labels. A total of 60,000 bottles are automatically inspected at our visual inspection station. And the recorded testing results are shown in Table 1. Furthermore, we sort out all glass bottles with defect labels to run a repeated defect detection test since the quantity of defect labels is little compared to the good samples. The stability testing results of our machine vision system are presented in Table 2.

It is noted from our experimental result that the overall accuracy of our method for transparent labels defect detection is 99.51% which is qualified for on-line manufacturing. Among them, for the character golden edge and small scratch, after the repeated test, the accuracy stays above 99.4%, which demonstrates the efficiency of propose adaptive visual inspection algorithm. However, from Table 2, we observe that the accuracy rate of bubble detection is relatively low compared to other defects. This is because the grayscale value of a bubble defect is close to the surrounding label grayscale in the image even special preprocessing filters are applied. In addition, from Table 1, it can be found that there is about 0.5% false detection which is from the inspection of good samples. The reason behind that is the quality of the printing label is not consistent as well as little rotation and position variation will change the captured image. If the algorithm is not robust enough, a few false detections will be generated especially some inevitable low-quality printing during scratch and character golden edge inspection.

Table 1. Online inspection result of glass bottle labels

Types of label defects	**QTY.**	**Correct**	**False**	**Accuracy**
No Defect	58548	58256	292	99.50%
Incomplete Label	1160	1158	2	99.83%
Small Scratch	47	46	1	97.87%
Label Bubble	44	44	0	100.00%
Labe Wrinkles	72	72	0	100.00%
Label Offset	102	102	0	100.00%
No Label	6	6	0	100.00%
Label crack	8	8	0	100.00%
Label Tilt	13	13	0	100.00%

Total	**60000**	**59706**	**294**	**99.51%**

Table 2. Repeated testing results of defects

Types of label defects	QTY.	Correct	False	Accuracy
Small Scratch	330	328	2	99.39%
Gold edges	378	377	1	99.74%
label bubble	360	359	1	99.72%
Label offset	251	251	0	100.00%
Label Wrinkles	230	230	0	100.00%

V. Conclusion

In order to implement automatic inspection of transparent printing label defect in curved surface glass bottle, we have designed and deployed an on-line machine vision system including image capture, processing algorithm and mechanical handling in a glass bottle manufacturing plant. A dedicated blue dome light was designed to acquire high quality standstill front and back label images using an area-array sensor in one trigger.

To overcome the challenging issues of curved surface with reflection interference, we introduced an adaptive visual inspection algorithm. The deformable template matching is able to handle the variable radius of the glass bottle shape. The combined global and local threshold idea successfully screens out small scratch. Skeleton extraction and distance transformation are applied to detect defect on the edge contour. The 60,000 samples run-off test indicates our machine vision inspection system can detect 8 types of label printing defects with an accuracy of 99.51% on-line. In the future, we plan to evaluate the performance of innovative learning algorithms such as convolutional network to develop efficient detection model and develop automatic visual inspection system for stain check on the bottleneck of a glass bottle. It will be also interesting to investigate the possibility for speeding up imaging processing in order to meet higher cycle time demand in this manufacturing line.

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