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Research on Real-Time Quality Inspection of PET Bottle Caps

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***Abstract* - Online quality inspection is an effective way to guarantee the quality of PET bottles packaging on the high-speed filling production line. This paper focused on studying and developing a machine vision inspecting system for on-line defects detection of PET caps without support rings. An image processing algorithm was proposed to detecting the serious defects such as surface foreign matters and link ring broken of the PET caps. For detecting the defect of surface foreign matters , the algorithm employed a mean filtering to estimate the background, then compared the inspected image with the background image by using dynamic threshold, as a result, the crack region was extracted. As to defect of link ring broken, the uneven gray-scale distribution in the RGB color space was extremely improved by HSV color space transform. Compared three components of HSV images, the gap feature between the cap and the link ring was more obvious in the saturation image. Hence, the gap region was extracted through segmenting the saturation image. Experiments demonstrate that the designed inspection system has an accuracy up to 97% and the speed up to 34000 bottles per hour.**

Index Terms - PET caps; online quality inspection; dynamic threshold

I. INTRODUCTION

Polyethylene terephthalate (PET) with its superior physical and chemical properties and cost performance, has been widely used in food and pharmaceutical packaging industry[1]. However, during the bottles and caps assembly process, defects such as tilted caps, high caps, link ring crack and surface foreign matter appear frequently. Consequently, the existence of these defects seriously affects the quality and safety of food and medicine. Generally, the defects inspection of PET caps mainly relies on manual, which is heavy workload, low efficiency, poor accuracy and high false rate[2]. However, machine vision system, with the advantages of non-contact, high efficiency and accuracy, has been widely employed in quality inspection and estimation of modern industry manufacturing.

Researchers have developed a variety of machine vision systems for PET caps inspection. However, most of relative works described in literature are concentrated on segmentation and recognition the support rings of the PET bottles and the inspection systems designed in these works can only detect defects such as bottles without caps, high caps, tilted caps, link ring completely broken[3-6]. However, when it comes to surface foreign matters and link ring partly broken, the existing inspection systems are out of function.

This paper designed a machine vision system which can implement the on-line quality inspection of PET bottles without support rings and the algorithm developed for the inspection system is based on color space transformation and dynamic threshold segmentation. The designed system not only can detect common defects such as bottles without caps, high caps, tilted caps, link ring completely broken, but also can inspect surface foreign matters and link ring partly broken. Now, the machine vision system has been installed on the PET bottled pharmaceutical production line with a speed up to 12,000 bottles per hour and detection accuracy up to 99%.

II. COMPONENTS OF THE INSPECTION SYSTEM

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The inspection system is composed of image acquisition unit, image processing unit, PLC control unit, pneumatic actuator and so on. The image acquisition unit mainly includes an IPC, LED light sources, Lens, and CCD cameras. Fig.1 shows the schematic diagram of the image acquisition unit, which contains three CCD cameras and the angle between two of them is 120°, as a result, the whole surface of the caps can be grabbed without rotating the bottles. When the bottles move on the convey belt, the photoelectric switch was triggered and the three CCD cameras were triggered simultaneously by the PLC to grab the images of the caps. Then the grabbed images were transferred to the image processing unit. Finally the recognition results were send to PLC by I/O ports and the pneumatic actuator were activated to remove the defect products.

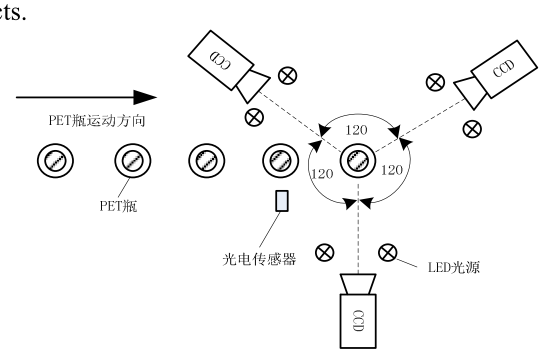

Fig.1 Schematic diagram of the image acquisition unit

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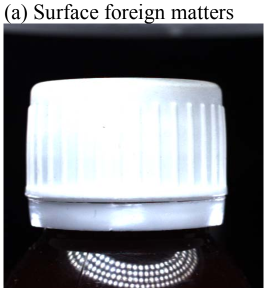
III. DEFECTS DETECTION OF PET CAPS

A. Common defects of the PET Caps

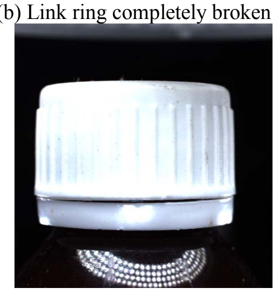
The common defects of the caps include bottles without caps, high caps, tilted caps, link ring completely broken, link ring partly broken and surface foreign matters. For detecting defects such as bottles without caps, high caps, tilted caps, link ring completely broken, several Commercialized inspection systems have been developed, while they are disable to detect link ring partly broken and surface foreign matters. This paper focuses on surface foreign matters, link ring completely broken and link ring partly broken as shown in Fig.2.

(a) Surface foreign matters

(b) Link ring completely broken



(c) Two connecting bridges broken



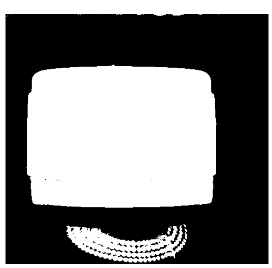
(d) Three connecting bridges broken

Fig.2 common defects of PET caps

B. Segmentation of PET caps

The PET bottles used in the pharmaceutical package are brown and the caps are white, Fig.3a shows the cap area image. From Fig.2a, we can easily find that the gray values of cap area are obviously higher than that of bottle body and background, hence, we can use simple threshold segmentation algorithm to extract the cap area. Fig.3b shows the cap area segmented by a threshold value 100. However, the binary image of the cap has noise caused by a reflection in the bottle area, therefore we use an area threshold to eliminate the noise. Fig.3c shows the cap binary image without noise.

(a) Original image



(b) Binary image with noise

(c) Binary image without noise

Fig.3 Threshold segmentation of cap images

C. Detecting surface foreign matters

Generally, the foreign matters on the cap surface appear as residual liquor, as shown in Fig.3a. The residual liquor on the cap surface Seriously affects the product quality and product reputation, so these defective products must be removed. However, the gray-scale distribution on the cap is uneven because of curved surface and non-slip bars. Hence, direct use of simple threshold to segment the defect area will lead to higher false negative and false positive. The literature[7] proposed an method based on illumination-reflectance model to correct uneven gray-scale images and the gray-level rectification process contains center transform, discrete Fourier transform, low-pass filter design and inverse Fourier transform, while the algorithm is complex and large amount of calculation. In this article, the author proposed a simple method which only contains background modeling, Image comparison and dynamic threshold to detect the defect area on the cap surface.

Let f (x, y) denotes an image, h (x, y) denotes a certain form of filter and the filtered image can be expressed as

$$g(x,y) = f(x,y) \otimes h(x,y) \tag{1}$$

Where g (x, y) represents the filtered image, $\otimes$ indicates convolution. The key of background modeling was filter design. According to experiment, the filter size is more important than that of the filter type. Too small size of filter leads to poor estimation of real background and causes false negative,while too large size of filter leads to huge amount of calculation and causes false positive. Therefore, when refers to the determination of filter size, we should take image resolution and the minimum size of the target into account. In this paper, we used a 150×150 mean filter to estimate the background, and Fig.4 shows the Fig.2a filtered by the designed filter above. From Fig.4, we find that the uneven distribution of gray-scale is improved obviously.

After establishing the background image, we compared the inspected images with the background image pixel by pixel and chose the pixels satisfying the equations (2) and (3), then collected these pixels into set S.

$$S = \{(x,y) \in R \mid g(x,y) - f(x,y) \geq T_{diff}\} \tag{2}$$

$$S = \{(x,y) \in R \mid g(x,y) - f(x,y) \leq -T_{diff}\} \tag{3}$$

Where, R represents the domain of the image, T_{diff} represents dynamic threshold. Equation (2) is appropriate for high gray-scale segmentation, while Equations (3) for low gray-scale segmentation. Fig.5 shows liquid residue region extracted by the above method, still contaminated by noise. Hence, we applied a morphological opening operation and an area threshold to remove the noise, as shown in Fig.6

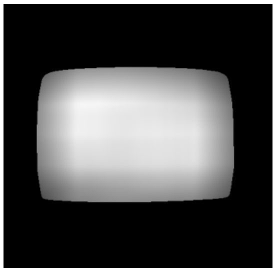


Fig.4 Background image

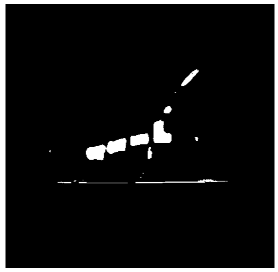


Fig.5 Liquid residue with noise

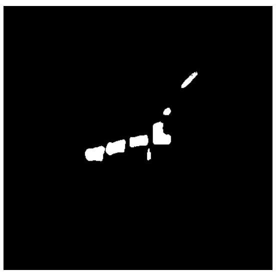


Fig.6 Liquid residue region without noise

D. Inspecting link ring broken

Link ring broken, as one of the most serious drug packaging quality defects, will lead to drug deterioration. The link ring broken can be divided into completely broken(as shown in Fig.3b) and partly broken(as shown in Fig.3c and 3d). The feature of link ring completely broken can be described by aspect ratio, while the feature of link ring partly broken is not obvious. When several connecting bridges are broken, as shown in Fig.3c and Fig.3d, the gap height between the cap and the link ring is only 0.2-0.3mm. Meanwhile, the cap is not in the same plane as the link ring, which leads to uneven gray-scale distribution in the region where the cap contacts the link ring. Therefore, it is difficult to extract the gap region by a single fixed threshold. Considering that the features of link ring partly broken is not obvious in the RGB color space, we attempt to utilize color space transform to detect the defect of link ring partly broken. HSV color space, as one of the most important color spaces, is widely used in image enhancement, image segmentation, color analysis, moving target tracking and so on[8]. The transformation model from RGB color space to HSV color space is as follows:

$$\max = Max\,[R, G, B]$$

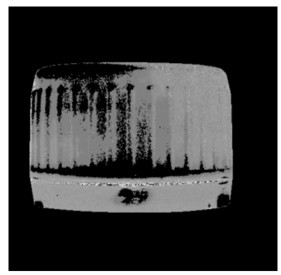
$$\min = Min\,[R, G, B]$$

$$H = \begin{cases} 0 & if \max = \min \\ \frac{\pi}{3} \times \frac{G-B}{\max - \min} & if \max = R \quad and \quad G \geq B \\ \frac{\pi}{3} \times \frac{G-B}{\max - \min} + 2\pi & if \max = R \quad and \quad G < B \\ \frac{\pi}{3} \times \frac{G-B}{\max - \min} + \frac{2\pi}{3} & if \max = G \\ \frac{\pi}{3} \times \frac{G-B}{\max - \min} + \frac{4\pi}{3} & if \max = B \end{cases} \tag{4}$$

$$S = \begin{cases} 0 & if \max = 0 \\ \frac{\max - \min}{\max} & otherwise \end{cases}$$

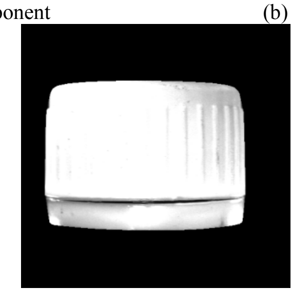
$$V = \max$$

Fig.7 shows each component image after HSV color transform. After comparing, we find that the gap feature is more obvious in S component. Fig.8 shows the gap region segmented using S component.



(a) H component

(b) S component



(c) V component

Fig.7 HSV images

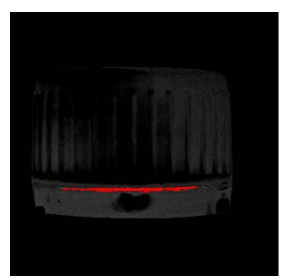


Fig.8 Gap region segmented by S component

IV EXPERIMENTS

Before the experiment, we chose 1000 normal caps, 100 caps with foreign matters, 100 caps with connecting bridges completely broken and 100 caps with connecting bridges partly broken. The application development environment was based on Visual C#2013 and OpenCV. While the application was running in the IPC(Inter Core i5-3470 with 4G RAM), it took 85ms to process a frame of image. Therefore, the inspection speed was so fast that it can easily satisfy the requirement of the pharmaceutical factory to detect 12,000 bottles per hour. Table1 shows the experiment results, and we can find that the inspection accuracy for normal caps and link ring completely broken is approximate 100%. For caps with foreign matters, because of uncertain size, shape, position and color of foreign matters, the accuracy is only 92%.

TABLE I
Results of the experiment

Test items	Numbers	False reject	Accuracy/%
Normal caps	1000	3	99.97
With foreign matters	100	8	92
Ring completely broken	100	0	100
Ring partly broken	100	3	97.0

V. CONCLUSION

In this article, the author proposed a detection method for PET bottles without support rings. Compared with the existing algorithms, the proposed method did not rely on detecting and positioning the support rings. Furthermore, the method was capable of inspecting defects of surface foreign matters and link ring partly broken. Presently, the designed machine vision inspecting system has been mounted on the pharmaceutical factory production lines, and the system is running well with a detecting accuracy up to 97.2%.

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