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Full Length Article

Research and implementation of machine vision technologies for empty bottle inspection systems

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ABSTRACT

Key technologies in empty bottle inspection systems are studied in this paper to solve detecting error and poor adaptability problems. Those technologies have two different approaches: the ones in the first group locate and track bottle mouth, bottle bottom and walls while the other group technologies involve defect detecting. Such vision inspection systems are required to perform with high accuracy and adaptability under high speed and mechanical vibration working conditions. This study proposes distinctive algorithms for bottle locating, tracking and defect detecting based on inspection requirements and images of bottle mouth, bottom and walls. On the premise of satisfying the inspecting requirements, the simplicity, ease of implementation and universality of the algorithms are considered to improve the detection speed and the adaptability of the system to different kinds of bottles. Experiments showed that the system proposed in this paper can improve the detection accuracy and speed.

1. Introduction

Glass bottles in beer filling line must be inspected prior to filling. Located after the bottle washing machine and before the filling machine, an quality inspection system is used to inspect empty bottles on line as an important component of the automatic filling line [15]. It is an intelligent equipment with machine vision, precision machinery and real-time control, which mainly consists of pre-inspection unit, wall inspection unit, mouth inspection unit, bottom inspection unit, control unit and human–computer interaction unit and man–machine interface unit, as shown in Fig. 1. The main functions include bottle mouth breakage inspection, the dirt and foreign body inspection of the bottle mouth, bottom and the wall and rejecting the bottles unqualified in time [11].

The research of beer bottle inspection using machine vision technology began in the 1990s. At present, some big companies, such as Heuft, Krones, Miho in Germany and Filtec in America, have their own empty bottle inspection systems, which have been applied to beer beverage production lines. The study of an empty bottle inspection system mainly focuses on how to improve the detection accuracy, speed and reliability. Moreover, the above products mentioned are not ideal in practical application in some countries due to the beer and beverage industry standards are different from country to country. In China, for example, the low quality and reutilization of empty bottles often lead to high false detection rate [8]. Therefore, it is still a hotspot for research and development of an empty bottle detection system. [22,25] designed an empty bottle defect detection system, respectively. However, they did not specify the implementation and performance of the system. He [6] described the methods of image acquisition and processing, but there is no further discussion on how to do that. The authors in Refs. [14,16,17,26] researched the location of empty bottles and realized the tracking of bottle mouth and bottom image. A method of bottle mouth inspection based on Extreme Learning Machine is proposed in Ref. [13], and the detection rate can be reached to 99.41%. Huang et al. [7] researched the method of bottle defect classification and realized the recognition of bottle mouth defects using Support Vector Machine with recognition rate 91.6%. In addition, some methods about defect detection of bottle mouth are described in Ref. [12,23,3,19]. Jaina George et al. [2] researched defect detection of bottle wall based on Fuzzy C Means Clustering. The authors in Ref. [5] proposed an algorithm of bottom detection and achieved good results. To solve the problem that detection result is affected by pattern on glass bottle, Zheng et al. [27] propose a glass bottle texture area detection algorithm of phase only based transition, which can achieve the detection rate 97%. However, the studies above just involve in some aspects of empty bottle vision inspection system, and the results are not satisfactory. Therefore, the key technologies of empty bottles visual

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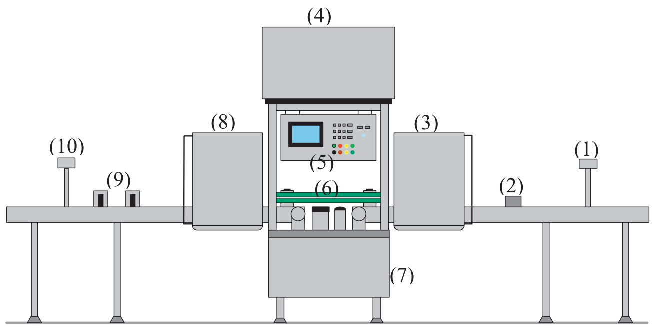

Fig. 1. Structure diagram of the empty bottle inspection system (1) Initial inspection (2) Residual liquid inspection (3) Bottle wall inspection (4) Operation and control unit (5) Control panel and bottle mouth image acquisition device (6) Bottle bottom image acquisition device (7) Gearing (8) Bottle wall inspection (9) Reject apparatus (10) Rejection confirm.

inspecting are studied in this paper based on Refs. [20,10,24,14,15,16,17,21,5], and the methods presented are successfully applied to the inspection system.

The rest of the paper is organized as follows. Section 2 describes the inspection area location and tracking. Section 3 expresses visual defect detection algorithm of empty bottles. Experimental results and discussion are reported in Section 4. The conclusion is presented in Section 5.

2. Inspection locations of bottles and their tracking

2.1. Bottle bottom inspection

2.1.1. Image preprocessing

Because of the high speed movement of empty bottles on transmission, the original images captured by CCD camera are not ideal such as noise interference and uneven illumination, which may appear when the target deviates from the center of the light source. Therefore, five nearest neighbor smoothing filter is used to remove noise and Eq. (1) is employed to achieve the grayscale transformation to enhance image contrast and improve the effect of output images.

$$g(x,y)=\begin{cases}\frac{11}{27}[f(x,y)-120]+200 & 120\leqslant f(x,y)\leqslant 255\\ \frac{37}{18}[f(x,y)-30]+15 & 30\leqslant f(x,y)<120\\ \frac{1}{2}f(x,y) & 0\leqslant f(x,y)<30\end{cases} \quad (1)$$

where $f(x,y)$ is the original image and $g(x,y)$ is the image after grayscale transformation.

2.1.2. Edge detection

After enhancing the contrast of images, edge detection of a bottle bottom is achieved in this paper using the following algorithm [1].

Step 1. Smooth the image using the equation as follows.

$$G(j,k)=G_0(j,k)\times F(j,k) \quad (2)$$

Here, $F(j,k)$ and $G(j,k)$ denote images of input and output. While $G_0(j,k)$ is filter template, and $G_0(j,k)=\frac{1}{2\pi\sigma^2}\exp\left(-\frac{j^2+k^2}{2\sigma^2}\right)$, σ^2 is variance, which shows the range of smooth.

Step 2. Find out the partial derivatives (G_x,G_y) of image gray level along the two directions using derivative operator and obtain gradient.

$$|G|=\sqrt{G_x^2+G_y^2} \quad (3)$$

Step 3. Calculate the gradient direction

$$\theta=\arctan\theta\left(\frac{G_x}{G_y}\right) \quad (4)$$

Step 4. Apply non-maximum suppression on dense edge points from gradient operation. The non-edge points can be eliminated along the gradient of the contour. Through the direction of the gradient, the adjacent pixels of one pixel in the direction of the gradient can be fixed. If the amplitude of the central point in the neighborhood is not larger than that of the two adjacent points in the direction along the gradient line, then this point is a non-edge point.

Step 5. Calculate thresholds using cumulative histogram. All pixels that their gradient values are larger than the high threshold must be elements of the edge; those which are smaller than the low threshold must be not. When the gradient value of a pixel is between the high and low thresholds, whether the pixel is one element of the edge depends on its adjacent pixels. If there is pixel belonging to the edge in its adjacent pixels, then it is; otherwise, it is not. If there are, then it is; otherwise, it is not.

2.1.3. Bottom positioning

In the process of empty bottles transmission at high speed, the bottle bottom position in each image may vary because of mechanical vibration and time error of image acquisition. Therefore, it is necessary to calculate the position of the bottle bottom in each image accurately to ensure it is in the region of interest. In practical application, the required velocity of empty bottles detecting is up to 20 bottles/s, so it is crucial to develop a quick and efficient positioning algorithm to improve the performance of the system.

Bottom positioning is actually circle detection in the image of a bottle bottom. Therefore, in order to obtain all parameters of the circle quickly and efficiently, the clutter edge is filtered first and then gets the parameters of the circle on this basis.

After edge detection, the image of a bottle bottom contains abundant edge information, in which some edges unimportant or irrelevant to bottom positioning will influence the effect of location greatly. Therefore, these unnecessary edges must be filtered.

Firstly, calculate the perimeter of each edge using equation as follows.

$$perimeter=n_e+\sqrt{2}n_0 \quad (5)$$

Here, n_e is the number of the chain code with even numbers, and n_0 is the number of the chain code with odd numbers. The even numbers in the chain code represent horizontal and vertical directions, and the odd numbers represent the other directions.

Then the unnecessary edges can be removed according to the perimeter threshold set after calculating each edge perimeter by Chain-code tracing.

After clutter edge filtering, the algorithm shown in Fig. 2 for circle detection is employed to improve the real-time performance of circle detection, and the specific steps can be obtained from the figure. Where D is an edge point set, p is circle parameter, P is a unit set of circle parameter, K is cycle times, and M_{min} is the set value of the minimum pixel number of a circle.

The results of bottom location are shown in Fig. 3.

2.2. Bottle mouth inspection

Bottle mouth location and tracking are the most difficult tasks in empty bottle vision inspection. The speed and accuracy of this step have a great influence on the performance of the inspection system. The region of interest in a bottle mouth image is defined in order to improve the processing speed. The regions of three rings in the image are defined as areas A, B and C successively, as shown