Research and Application of Label Defect Detection Method Based on Machine Vision

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Abstract. For the problems of scratches and false detections such as wrinkles and other defects in the printing process, the HALCON software is used for programming, and the product label defects are detected in real time based on the photometric stereo vision technology. Firstly, by dimming the product labels of four different orientations, different orientation maps are obtained, the illumination map is calculated to obtain the albedo map, and then the four-source photometric stereo technology is used on the basis of the traditional photometric stereo technology. After obtaining the surface gradient information of the tag to be tested, the measurement image is subjected to morphological processing using the gradient information to obtain a curvature image. The curvature image is then image processed. Finally, the defective portion is filtered to effectively segment the surface defect area of the label. This method is implemented using HALCON software and is implemented in conjunction with C# mixed programming.

1. Introduction

Product labeling is a special carrier related to product information, corporate culture and image, so its importance is becoming more and more important in people's growing consumer demand [1]. In the past, the standard label comparison method was used to evaluate the appearance of the product label. The method is subjective and compares the label to be tested with the defect-free label by visual measurement under standard lighting conditions. Due to the influence of human factors, it is easy to produce errors by using this method for experiments. Therefore, objective evaluation of label performance, such as label scratches and wrinkles, has become essential. The surface of the label with defects such as scratches and wrinkles has a significant curvature change, which can be used as an important feature for detecting label defects.

As the field of machine vision gradually enters people's attention, real-time detection technology based on machine vision is gradually replacing artificial work [2]. Thanks to its easy-to-control, fast and real-time processing of information, machine learning has been rapidly developed in the field of real-time detection of defects in the printing industry [3-4].

In recent years, 3D reconstruction technology has been gradually applied to the objective evaluation system of the printing industry as a new reconstruction method. In 2018, Ren M et al. [5] extended the technique to non-Lambertian surface detection using the traditional Photometric Stereo (PS) technique. This method has extremely high accuracy and efficiency in surface normal estimation.
Literature [6] developed a three-dimensional defect on-line detection system based on photometric stereo, and the performance of the surface inspection system has been significantly improved. Literature [7] proposed a model-based visual inspection of tablets for detecting surface defects that occurred during tableting. The method was tested on two groups of tablets and compared to prior art methods. Lee et al. [8] proposed an artificial intelligence automatic defect detection system based on deep learning technology in the literature, which uses the fused illumination image to simultaneously acquire the 2D and 3D information of the target object. Label defect detection is mainly composed of three main processes: label image acquisition, image preprocessing, defect detection and display defect. It mainly includes the use of industrial cameras and lenses to collect images. Through common image processing methods, including image fusion, image segmentation, morphological processing, and the like. The collected image of the to-be-detected label is improved, and each defect image area to be detected is obtained, which facilitates analysis and recognition of the image features of the relevant defect, and finally displays the result of the detection through a program.

2. Detection principle
Because the traditional photometric stereo technology is susceptible to various external factors, the detection results are not satisfactory. In order to reduce the impact of these factors and improve the detection rate, this paper uses four-source photometric stereo technology, and on this basis, the requirements are increased, so that the surface gradient of the image to be tested can be obtained more accurately, thereby improving the detection rate.

2.1. Four-source photometric stereo technology
We can get the brightness of the reflected light of a certain pixel in the four images taken by the camera from different light sources. Where I1, I2, I3, and I4 represent:

\[
\begin{align*}
I_1 &= \rho L_1 N \\ I_2 &= \rho L_2 N \\ I_3 &= \rho L_3 N \\ I_4 &= \rho L_4 N
\end{align*}
\]

Convert the above formula to a matrix form to get its matrix formula:

\[
\begin{bmatrix}
I_1 \\
I_2 \\
I_3 \\
I_4
\end{bmatrix} = \rho \begin{bmatrix}
L_x^1 & L_y^1 & L_z^1 \\
L_x^2 & L_y^2 & L_z^2 \\
L_x^3 & L_y^3 & L_z^3 \\
L_x^4 & L_y^4 & L_z^4
\end{bmatrix} \begin{bmatrix}
N_x \\
N_y \\
N_z
\end{bmatrix}
\]

The solution of equation (2) can be found by the least squares method.

\[
\rho = \frac{\| (L^T L)^{-1} (L^T I) \|}{\| (L^T I) \|}
\]

\[
N = \frac{(L^T L)^{-1} (L^T I)}{\rho}
\]

Finally, the surface gradients p and q of the object to be tested can be obtained.

\[
p = \frac{(L_x^2 L_z^4 - L_y^2 L_z^4)^{-1} (L_x^4 I)}{(L_x^2 L_z^4 - L_y^2 L_z^4)^{-1} (L_y^4 I)}
\]

\[
q = \frac{(L_x^2 L_z^4 - L_y^2 L_z^4)^{-1} (L_y^4 I)}{(L_x^2 L_z^4 - L_y^2 L_z^4)^{-1} (L_x^4 I)}
\]

It can be seen from the above formula that the method can obtain the gradient information of the surface of the label image more accurately. This laid a solid foundation for the next experiment.

2.2. Surface Gaussian curvature
In the industry, the surface height information can not accurately identify and detect the label defect information, and the surface curvature information is often obtained according to the surface height
information, and then the defect portion is identified, thereby detecting the label defect more efficiently.

The function \( f(r, c) \) is surface gradient information, and Gaussian derivative convolution is performed on its row and column components.

\[
\begin{align*}
\mathbf{f}(r, c) &= (u(r, c), v(r, c)) \\
\mathbf{u}(r, c) &= \frac{\partial f(r, c)}{\partial r}, \\
v(r, c) &= \frac{\partial f(r, c)}{\partial c}.
\end{align*}
\]  

In the formula, \( r \) is the row coordinate in the image; \( c \) is the column coordinate in the image; \( u(r, c) \) and \( v(r, c) \) are the row and column gradient components at the point \((r, c)\) of the surface of the object to be tested, respectively, and their values are \( p \) and \( q \), respectively.

Surface Gaussian curvature is:

\[
K = \frac{\partial^2 f(r, c)}{\partial r^2} \frac{\partial^2 f(r, c)}{\partial c^2} - \frac{(\frac{\partial f(r, c)}{\partial r})^2}{(1 + (\frac{\partial f(r, c)}{\partial r})^2)^2} \tag{8}
\]

After obtaining the Gaussian curvature \( K \) value of the label image, it is necessary to convert the Gaussian curvature of each point on the image into a gray value, that is, the Gaussian curvature of the surface of the measured object is converted into a curvature image. Finally, the curvature image is segmented using a threshold to detect the label defect.

2.3. Label surface defect detection

2.3.1. Scratch defect detection

The scratched area is relatively large with respect to other areas on the surface of the label, and the gray value is large. The four-source luminosity stereoscopic technique will enhance the scratched area, and the scratch defect is more prominent, but the general image has more noise, so the gray An increase in the degree is likely to cause interference. In order to suppress the influence of noise, the emphasize operator is first added to enhance the image, then the defect image is segmented by BLOB analysis, and then the image is processed by expansion etching and opening and closing operations. Finally, scratch defect detection is achieved. Figure 1 shows the effect of the proportion of samples to be detected on the detection accuracy of scratch defect detection.

2.3.2. Fold defect detection

The pleated area is relatively dim in the image, and its gradation value is relatively low. Therefore, the detection method is different from the scratch area. Since there are more individual noise points in the image, the median value is used on the basis of the four-source luminosity stereo method. The filtering method reduces these individual noises and identifies the pleated regions in combination with features such as connected domains. Figure 2 shows the effect of the proportion of samples to be detected on the detection accuracy of the pleat defect detection.
3. Experiment

3.1. Data set and hardware parameters
In this paper, the product label is taken as the research object, and two kinds of defect labels with scratches and wrinkles are collected. Each group has 254 sets of data and experiments are carried out separately. The hardware part of the experiment is a digital camera produced by China Daheng Company. The specific parameters are shown in Table 1.

| Model               | MER-133-54GM-P     |
|---------------------|--------------------|
| Interface           | GigE- Vision       |
| Resolution          | 1280(H) × 960(V)   |
| Frame Rate          | 54fps              |
| Sensor Type         | 1/3''ON AR0135 frame exposure CMOS |
| Pixel Size          | 3.75μm×3.75μm      |
| Lens Interface      | C port             |
| Laser Structure     | Telecentric macro structure laser |

3.2. Software Implementation
Tag defect detection is implemented using HALCON and C# hybrid programming. Adding four images taken from different light sources to the label defect detection software for synthesis and surface defect detection, as shown in Figure 3.

3.3. Experimental testing and analysis
Figure 4 is a comparison of the accuracy of the label wrinkle defect, wherein the accuracy is the ratio of the defect extracted by the three-dimensional reconstruction technique to the total defect image. It can be seen from the figure that the accuracy of the algorithm used in this paper is significantly higher than that of binocular stereo vision technology and traditional photometric stereo vision technology.
In this paper, two defects of scratch and wrinkle on the surface of the label were tested. The test results are shown in Table 2. It can be seen from the table that compared with the traditional photometric stereo geometry technology, the detection accuracy of the method used in this paper is about 93% on average. This shows that the method can detect the surface defects of the label more accurately and has certain practical value.

Table 2. Detection data for different label defects.

| Type     | Total sample | Number of correct | Number of errors | Accuracy/% |
|----------|--------------|-------------------|------------------|------------|
| Scratch  | 254          | 236               | 18               | 92.91      |
| Fold     | 254          | 238               | 16               | 93.70      |

Acknowledgments
This topic was completed in the course of selecting the topic and the research process with the kind care and careful guidance of the teacher and the help of the same door. Mr. Ren not only gave me meticulous guidance in her studies, but also gave me meticulous care in my thoughts and life. I would like to extend my sincere gratitude and lofty respect to Ren and his colleagues.

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