Defect detection algorithm of plastic 3D paint surface based on image fusion

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Abstract—In this paper, we proposed a new novel algorithm to detect defects cataloged as dings, dents and scratch on plastic 3D paint surface using patterned illumination. This algorithm first fuses the continuous images through different ways to obtain one fused image, which is obtained by patterned light illumination. Then, a series of morphological operations are used to obtain high-contrast image for subsequent feature statistics and defect screening. Experiments show that real-time inspection can be achieved, and the detection of plastic 3D paint surface defects can be completed within 13s, with an accuracy of 86%.

1. INTRODUCTION
Defect detection on plastic 3D paint surface is a hot topic in the industry. The customer has very high requirements on the plastic surface. Due to the complex shape of the non-planar plastic painted surfaces, ordinary imaging methods such as dark field illumination and bright field illumination often do not achieve very good results. Therefore, based on the principle of deflectometry[1], we design a system to project the stripe light[2] and move the stripe to get a series of images. Through a novel image fusion method, a series of images are finally merged into an image that highlights the features of the defect.

2. DETECTION SYSTEM AND LIGHTING PRINCIPLE
As shown in figure 1(a), we design a system that can move a striped light source[3]. The stripe light source of this system can move at a uniform speed. During the movement of the light source, we will acquire a series of images at the same interval for later image fusion. It can be seen from figure 1(b) that due to the existence of defects, the light that should have fallen into the dark area fell into the illuminated area through deflection, which caused bright spots in the dark area. By moving the light source, the contrast is highest when the defect is close to the bright-dark band boundary.
3. DEFECT DETECTION ALGORITHM

As is shown in figure 2, the algorithm is divided into Pre-Process and Post-Process. This paper will focus on pre-process. The purpose of Pre-process is to obtain an image that can highlight the defects on the plastic surface through a series of image fusion and image enhancement operations. The purpose of Post-process is to perform a series of feature calculation and classification on the binary map obtained by the previous Pre-process, and finally screen out the defects that meet the requirements and get their positions and various parameters. This paper will focus on pre-process.

3.1. Image fusion

The purpose of image fusion is to fuse multiple time-phase information of a certain perspective camera to highlight certain features[4]. We followed two principles in the process of image fusion. First, try to save as much information as possible. Secondly, minimize the effects of diffused light. Therefore, we creatively proposed two ways of image fusion, and finally operated the two fused images to obtain the target image $I_f$. As is shown in figure 1, these images are three frames of original images.

$$I_f = \max(|I_k - i_{k*}|), k = 1..(n-m)$$  \hspace{1cm} (1)
Where $i_k$ is the kth frame of the images, $n$ is the total number of images. $m$ is the interval between subtracting two images. In the experiment, we take $m$ equal to 7.

According to the equation (1), we use two frames with interval $m$ to do the difference $|i_k - i_{k+m}|$. The use of difference can eliminate the effects of diffuse light on the plastic surface and can highlight defects more in the image $I_a$.

$$I_a = \max(i_k), k = 1..n$$

(2)

Where $i_k$ is the kth frame of the images, $n$ is the total number of images.

According to the equation (2), $I^*$ is the maximum gray value for each position in all images. The purpose is to better identify the area where the stripes are swept, and thereby estimate the background.

$$I^*_c = I^*_* \cdot S_1 - I_a$$

(3)

Where $S_1$ is the morphological structuring element (the size is 31 in the experiment). $\cdot$ is Closing operation (morphology).

According to the equation (3), we fuse the first two picture $I^*_a$ and $I^*$ into $I_c$ through morphological operation. The goal is to eliminate black belt problems caused by uneven lighting.

As shown in figure 3, we get a fusion map through a series of operations to facilitate subsequent image segmentation and defect extraction.

3.2. Get the Contrast map and Segmentation

By doing the difference, we get the contrast image through the top-hat operation [5]

$$I_{\text{contrast}} = (I_c - I_c \cdot S_2) \cdot \alpha + \beta$$

(4)

Where $S_2$ is the morphological structuring element (the size is 31 in the experiment), which is used for opening operation. $\circ$ is Opening operation. $\alpha$ , $\beta$ is the factor of contrast stretching ($\alpha$ is 3.0, $\beta$ is 30 in the experiment).

As is shown in figure 3(e), we can get the pixel location of the defect we need to detect by Hysteresis Thresholding [6] the contrast map. That means we will set up two thresholds, pixels with gray values above the high threshold will be preserved, and pixels with gray values below the low threshold will be discarded. Whether or not the pixel between the two thresholds is retained depends on whether he is connected to the pixel that has been reserved. In the experiment, we set the low threshold to 80 and the high threshold to 120. After getting the binary map through the above operations, we can proceed to the next post-process.

By extracting the connected domain of the binary map, matching the template to determine the ROI, performing feature calculations, and finally performing defect screening, we can mark defects and get their exact locations. The parameters for defect screening are controllable, and finally flexible threshold parameters can be set according to production needs.
4. EXPERIMENTAL RESULTS AND ANALYSIS

As shown in figure 4, defects on the plastic surface can be highlighted through image fusion under the action of a moving stripe light source. The algorithm can be used to find these defects and mark their location. In the actual experiment, the minimum size of defects required to be detected is $0.1 \text{ mm}^2$ (0.03 mm long). We used a lens with a focal length of 12 mm and a camera with a resolution of 50 $\mu\text{m}$. Therefore, the defect is at least 6 pixels wide in the image taken. In the test, the CPU of the computer we used was i7-9700k, and the GPU was RTX-2060. In actual experiments, the average time is within 13 seconds. The correctness of the algorithm can be measured from the accuracy of the experimental detection of defects.

$$\text{Accuracy} = \left(1 - \frac{\text{overcut} + \text{loss}}{\text{TotalNumber}}\right) \times 100\%$$

(5)

According to the equation (5), the correctness of the algorithm can be measured from the accuracy of the experimental detection of defects. In this experiment, the accuracy is 86%.

5. CONCLUSION

In this paper, a novel algorithm based on deflectometry techniques for detecting defects has been presented. We can get a set of images by using patterned illumination. Through the image fusion technology, an image with high defect contrast is obtained. This technology can help detect defects on
plastic surfaces. But there is still room for improvement in this algorithm. For example, the time required can be further shortened, and the number of overcut should be further reduced. Future work focuses on the selection and optimization of parameters in the process and the further optimization of algorithm time complexity.

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