# Scratch Detection Algorithm of Car Surface Based on Directional Color SUSAN Operator

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**Abstract:** The car surface scratch detection adopts the traditional manual detection with poor efficiency and high missing rate. Because of the gray mark and the background of car surface scratches, the traditional edge detection algorithm cannot meet the needs of car surface scratch detection. Therefore, the directional SUSAN algorithm based on CIELab color space is adopted in this paper. The direction template and the circle template to calculate the color difference of the color image are used in the algorithm which has been converted to the CIELab space. The edges and scratches are eliminated by matching and contrasting the detected image with the edge template. Experimental results show that the algorithm can effectively detect scratches on the surface of cars, improve the detection speed and reduce the undetected rate.

**Key words:** scratch detection; directional template; CIELab space; SUSAN algorithm

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## 0 Introduction

A large number of imported cars poured into the market. The car surface is inevitably scratched in transportation, but the quality of the car surface is directly related to the quality of the car. At present, the scratch detection of car surface mainly uses manual detection with low efficiency and high mission rate. Scratch is one of the edge features of the image, and scratch detection is to detect the edge of the surface without contour. In recent years, researchers have proposed different edge detection algorithms. Mathur et al. proposed an improved Sobel edge algorithm based on $K$-means clustering method[1]. Yuan et al. proposed an adaptive image edge detection algorithm based on Canny operator[2]. Qu et al. proposed fast small univalue segment assimilating nucleus (SUSAN) edge detection with adaptive step size[3]. Aslam et al. proposed the combination of Sobel and related thresholds, and found that different regions used contour closure algorithms[4]. Baris et al. proposed multiscale image detection and image processing[5]. Shamugavadivu et al. proposed an improved eight direction, i.e. Canny edge detection[6]. Wang et al. proposed that, based on the traditional Canny algorithm, adaptive filtering and morphological edge processing were used to improve the Canny edge detection algorithm[7]. Liu and Jezek proposed the method of automatically detecting the coastline of satellite images by using Canny edge detection and local threshold adaptive[8]. Savant proposed a gradient operator color image edge detection algorithm[9]. Melin et al. proposed an improved Sobel edge detection method based on generalized two type fuzzy logic[10]. Jaseema et al. proposed an adaptive iterative Canny algorithm in the detection of skin lesions[11]. Gao et al. proposed the comparative approaches for automated detection of hard exudates in fundus images[12]. Wu et al. proposed the edge detection of river in SAR image

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based on contourlet modulus maxima and improved mathematical morphology[13]. The above algorithm first converts color images into gray images, and then uses gray image edge detection operators to detect them. However, the grayscale of the scratch on the surface of the car is similar to that of the surface coating, so the algorithm itself loses part of the edges of the color image. Zeng proposed a color image SUSAN edge detection method[14]. Zhang et al. proposed the weighted neighbor-region based multi-level fuzzy edge detection method[15]. This method detects edges of images by fuzzy enhancement, but it cannot obtain good experimental results for cars. Wang et al. proposed the method of detecting curved edges in noisy images in sublinear time[16]. It is a multiscale scheme to detect curved edges. This scheme has no good effect on directional edge. Wang et al. constructed multi-directional, multi-scale top-hat operators to detect the edge of image, and combined the edges of the image detected to get final edge of image[17], while the method had no work for color image. Peng et al. proposed a new subpixel edge detection approach based on edge gradient directional interpolation and Zernike orthogonal moment[18]. The mirror reflection on the car surface results at a high false detection rate. Nasution et al. proposed improvements to edge detection method with the approach graph in the Ant Colony optimization algorithm[19], while the method did not work well for the surface of cars. And the method uses CIELab space to achieve edge detection, which ignores the direction of the edge, so it is not suitable for car surface scratch detection.

Therefore, scratch detection algorithm of car surface based on directional color SUSAN operator is proposed in this paper. The proposed algorithm uses the circular template to traverse the image and calculate the area of the Univalue Segment Assimilating Nucleus (USAN), then calculates the template pixels within the pixel and nuclear center pixel using directional template. The pixel difference is compared with the threshold to judge whether the mean between the pixel and the center pixel is used to fill the small hole. The algorithm can eliminate the internal noise and smooth the image.

## 1 Analysis of Car Edge and Scratch Characteristics

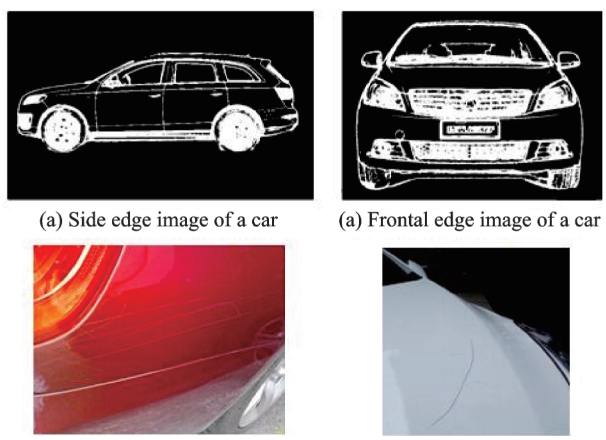
Car edge features have unique features compared with other image edges. As shown in Figs. 1(a) and (b), the edge of the car has a clear orientation, and there is no obvious change in the edge thickness. As shown in Figs.1(c) and (d), scratches on the surface of a car are equally distinctive:

(1) The shape of the scratches is long and narrow.

(2) Scratches have obvious directionality, even though the direction is uncertain.

(3) There are some small scratches. The brightness of the color and black body scratches area is brighter for the near non-scratch area, and the brightness of the white body scratches area is dark near the scratch area, but the small scratch is similar compared with the gray level of the entire image.

If the traditional algorithm based on image gray level is used to detect surface scratches, the detection rate will increase significantly. Therefore, this paper proposes a color space directional SUSAN algorithm to realize car surface scratch detection.



(a) Side edge image of a car (a) Frontal edge image of a car

(c) Scratch image of a color car (d) Scratch image of a white car

Fig.1 Edge and scratch of a car

## 2 The Proposed Algorithm

In the proposed algorithm, the color difference between scratches and non-scratches is utilized to improve the SUSAN algorithm for scratch detection. The image format is ".jpg". The algorithm flow of this paper is shown in Fig. 2. After reading the image, the image is converted to CIELab space image, and then the directional template is used to calculate the color difference between the pixel and the core. If the chromatic aberration is not greater than the threshold $T$, the color difference average is used to fill the hole. Then, the USAN area is calculated by the circle, and the edge of the car is output according to the size of the USAN. The contour of the car is removed by car template matching, and the scratch image is output.

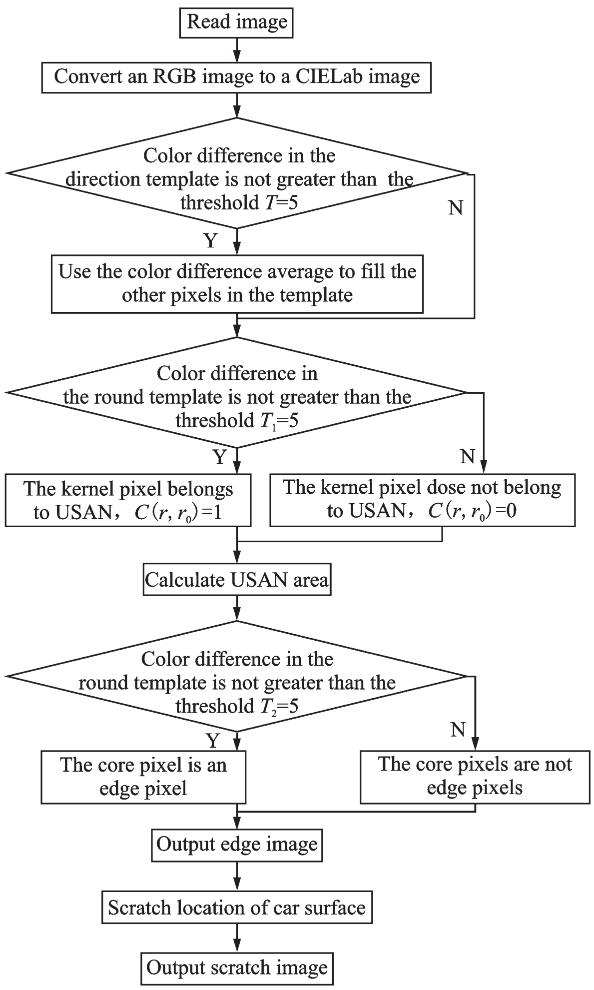



Fig.2 Flow chart of algorithm

## 2.1 CIELab color space conversion

As the close characteristic between the scratch gray value and the gray value of car coating, the traditional SUSAN algorithm based on gray level operation cannot meet the requirement of car surface scratch detection. This paper proposes an algorithm for color space SUSAN edge detection. Because the color images in RGB space are non-uniform space, the Euclidean space distance cannnot be used to identify the color differences between pixels in RGB color space. The RGB space needs to be converted to CIELab uniform color space, and then the Euclidean distance is used to calculate the color difference between two pixels.

The purpose of the CIELab color model (defined by CIE in 1976) is to linearize the color according to the perception of colors, and to create a more intuitive color system. The dimensions of the color space include brightness $L$ and two color components $a$ and $b$, where $a$ and $b$ are each along the green-red and blue-yellow axes to determine hue and saturation. At present, there are some specifications for converting in Lab space and other spaces. First RGB space is converted to CIEXYZ space, shown as

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 0.412\,4 & 0.357\,5 & 0.180\,4 \\ 0.212\,8 & 0.715\,2 & 0.072\,2 \\ 0.0.9\,3 & 0.119\,2 & 0.950\,2 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

Convert CIEXYZ to CIELab. The conversion specification is defined by the ISO standard as follows

$$\begin{gathered} L = 116 \times Y' - 16 \\ a = 500 \times (X' - Y') \\ b = 200 \times (Y' - Z') \\ X' = f_1(X/X_{\text{ref}}) \\ Y' = f_1(Y/Y_{\text{ref}}) \\ Z' = f_1(Z/Z_{\text{ref}}) \end{gathered} \tag{2}$$

$$f_1(c) = \begin{cases} c^{1/3} & c \leqslant 0.008\,856 \\ 7.787 \times c + 16/116 & c > 0.008\,856 \end{cases}$$

The chromatic aberration of two pixels in CIELab space can be modeled by Euclidean distance

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \tag{3}$$

## 2.2 Calculation of pixel similarity in template

The SUSAN algorithm is introduced into CIELab color space, and the SUSAN algorithm is based on USAN edge detection criteria. The criterion will be at the center of the graphics window template and wait for the detected pixels to become the central pixels (the core point). USAN moves on the image, and if the color and template nuclear center point is less than a given threshold value of the pixel color in the template, the pixel and the center point have the same core value. The typical location of USAN is shown in Fig.3.

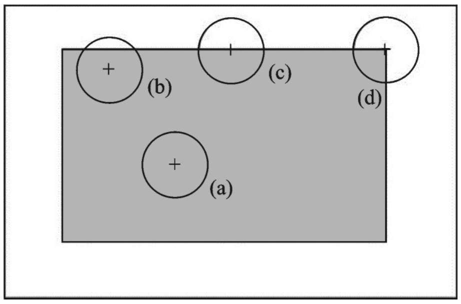



Fig.3 USAN typical location

Fig.3 clearly shows that when the core element points are at the edge, the USAN region accounts for only half, and when the core is at the corner, the USAN region is the smallest. It is not difficult to see that the USAN region contains the image edge structure information, and the area of the USAN region can be used as a description of edge features to measure the edge features.

A circular template can be choosen with radii of 3, 4 of the window. But considering the stability and accuracy of the SUSAN algorithm using approximate circular template, the template size is 7 × 7 and the radius is 4 pixels, as shown in Fig.4.

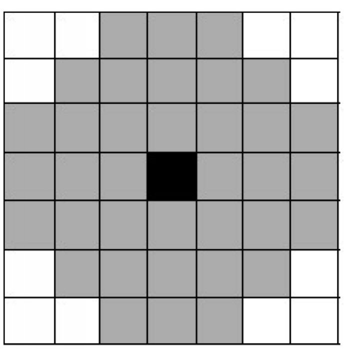


Fig.4 Circular template

The center of a circular template is the black square. The template window is sliding on the image. And the USAN size of each pixel is calculated.

In this paper, a directional template edge enhancement SUSAN algorithm is proposed to enhance the image edge according to the directional template. The main purpose is to compensate for the contour of the image and highlight the edge information of the image so as to make the image clearer.

The directional template edge enhancement SUSAN algorithm is based on CIELab color space. For the image converted to CIELab color space, 16-direction templates are selected to calculate the absolute value difference between the pixel value of the image to be processed (central pixel) and the edge pixels in each template. According to the absolute value of the difference, we can determine whether the pixel to be processed belongs to the USAN region. For pixels belonging to the USAN region, the average pixels of the central pixel and the edge pixels of the template are used to fill the other pixels in the template in this direction. As shown in Fig.5, the black block represents the pixel to be detected, and the gray block represents the neighborhood pixels of the pixel to be detected. The pixel blocks wrapped in dark lines are directional templates.

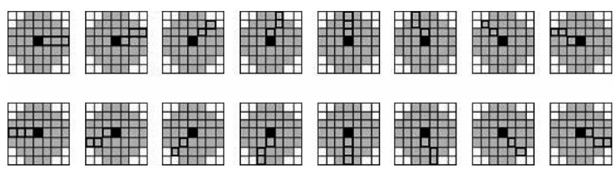


Fig.5 Directional templates

The edge of a color image is a region where the chromaticity of the interior pixels varies greatly. The improved SUSAN operator is applied to the edge detection of color images. First, the RGB image is converted to the CIELab color space. Then, the whole image is traversed with a circular template of radius 4, and the chromatic aberration of each pixel in the template and the kernel central pixel are calculated. The color difference between the central pixel and the pixels in the color template is shown as

$$\Delta E(r,r_0)=\sqrt{(L_r-L_{r_0})^2+(a_r-a_{r_0})^2+(b_r-b_{r_0})^2} \tag{4}$$

where $r$ represents the pixel in the template and $r_0$ the core pixel. The edge detection result is shown as

$$c(r,r_0)=\begin{cases}1 & \Delta E(r,r_0)\leqslant T\\ 0 & \Delta E(r,r_0)>T\end{cases} \tag{5}$$

where $T$ is the color difference threshold.

### 2.3 Directional image enhancement and edge determination

Calculation of central pixel in the direction template pixel according to the 16-direction template and to Eq.(5) is to determine whether a pixel belongs to the center area of USAN. If the central pixel belongs to the area of USAN, the nuclear center pixel color and template edge pixel are used to averagely fill other pixel on the template in this direction. The pixel mean is shown as

$$\Delta E(r,r_0)=\sqrt{(L_r-L_{r_0})^2+(a_r-a_{r_0})^2+(b_r-b_{r_0})^2}/2 \quad (6)$$

The size of the USAN is the number of similarities between the pixels in the circular template and the core pixels. The greater the value of the USAN region is, the more pixels in the pixel template are, which is similar to the core pixels. On the other hand, fewer pixels are similar to pixels in the core. Therefore, the USAN region size calculation formula is shown as

$$n(r_0)=\sum_r c(r,r_0) \quad (7)$$

SUSAN edge detection can obtain the initial edge response value of the pixel according to Eq.(8).

$$R(r_0)=\begin{cases} g-n(r_0) & n(r_0)<g \\ 0 & \text{Otherwise} \end{cases} \quad (8)$$

### 2.4 Scratch location of car surface

After the image edge detection process, the location of the scratch must be carried out. The main task of this section is to remove the non-scratch part of the edge image, so as to determine the position of the scratch in the body. Since the position of the system and the body remain unchanged during the process of obtaining the image, and the model of the car directly determines the shape of the body, the non-scratch part is eliminated by establishing an image edge template library. First, cameras are installed in five fixed positions of the front, back, left and right sides and top to photograph car images. Diagram of edge template is shown in Fig.6. Then, the edge template library is built using scratch free car images. In the same system environment, the car image to be detected is photographed and matched with the template in the template library to realize edge elimination and scratch localization. The car image to be detected is shown in Fig.7. In this paper, we extract the edge image feature curve, and then determine the rotation angle and displacement distance of the template in the edge image. Finally, we use the image registration technique to realize the scratch localization.

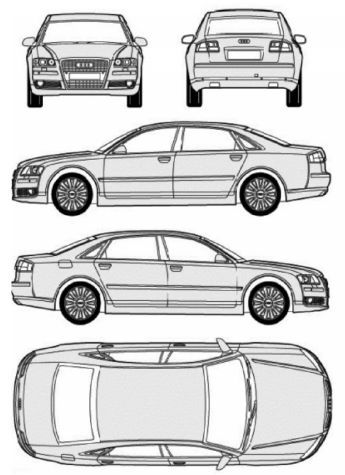


Fig.6 Diagram of edge template

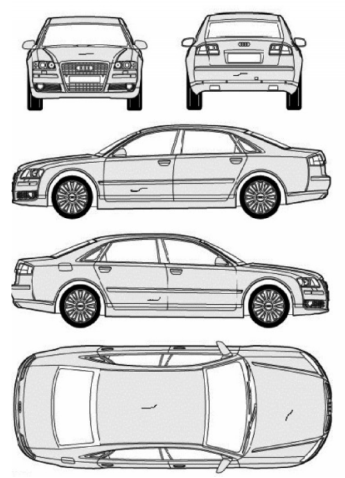


Fig.7 Car image to be detected

### 2.5 Algorithm implementation process

For the convenience of narration, the partial MATLAB statement format is adopted in the implementation of this algorithm.

Input: fin=imread("filename")

Output: imshow("image_scratch")

(1) Convert the RGB image to CIELab image, that is

Image_lab=RGB2CIELab("fin")

(2) Suppose that the gray image of the image has $i$ rows and $j$ columns. According to Eq.(4), the chromatic aberration between the pixel in the direction template and the central pixel is calculated iteratively. If $\Delta E(r,r_0)\leqslant T$, use the color average $E$ in Eq.(6) to fill the other pixels in the template.

(3) According to Eq.(4), the chromatic aberration between the pixel in the round template and the central pixel is calculated. If $\Delta E(r,r_0)\leqslant T$, the kernel pixel belongs to the USAN region and then we record $c(r,r_0)=1$, otherwise $c(r,r_0)=0$. Use Eq. (7) to calculate the USAN area. When the USAN area is less than the threshold $g=3\times 37/4$, the pixel point is the edge pixel point, $\mathrm{RH}(i,j)=g-n(r_0)$; otherwise $\mathrm{RH}(i,j)=0$. Traverse the entire image to step (4), or else go to step (2).

(4) Output edge image, that is

Image_out=RH($4:c-4,4:d-4$)

(5) Eliminate non-scratch parts.

The Image_out is used to match the edge template in the template library to eliminate the non-scratch part and output the scratch image.

## 3 Experiments

To verify the effectiveness of the proposed algorithm, 23 white cars and 21 red cars were used as scratch test samples, and the two-color samples have 200 scratches, respectively. The SUSAN edge detection algorithm, the algorithms in Refs. [15, 16, 18], the Top-hat operator, the Canny edge detection algorithm, the Sobel edge detection algorithm, and the proposed edge detection algorithm are used in the experiments. First, the algorithm in Ref.[15] computes the image gradient features, and utilizes the adaptive method to divide image into multiple tiers based on gradient. Then, a fuzzy function is constructed to strengthen different image gradient features in different levels. The basic principle of Canny edge detection is to firstly use the Gauss filter function for image filtering, image noise removal, calculation of gradient magnitude and direction of the image, and then use the first order differential. Then the maximum value of the gradient amplitude is suppressed, and the maximum value of the local gradient is retained. Finally, the double threshold method is used to detect and connect the edge. The basic principle of the Sobel algorithm is first to implement neighborhood averaging or weighted average, and then to perform first order differential processing, finally to use the horizontal gradient direction to detect vertical edge and vertical gradient direction. After detecting the horizontal edge, the horizontal and vertical gradient components are computed, respectively, and the gradient amplitude is calculated. If the gradient amplitude is greater than the threshold $T$, the pixel point is the edge point. In this paper, two thresholds are selected, $T_{so}=70$ and $T_{so}=100$, respectively. The traditional SUSAN edge detection method is to measure the gray image edge, and to set two gray thresholds $T_{su}=15$ and $T_{su}=30$. The threshold of the algorithm is 5, and the edge of color image is detected according to the fourth section algorithm. The edge detection results of the above algorithms are shown in Figs.8, 9. The average running time, average effective scratch length and undetected rate of each algorithm are shown in Table

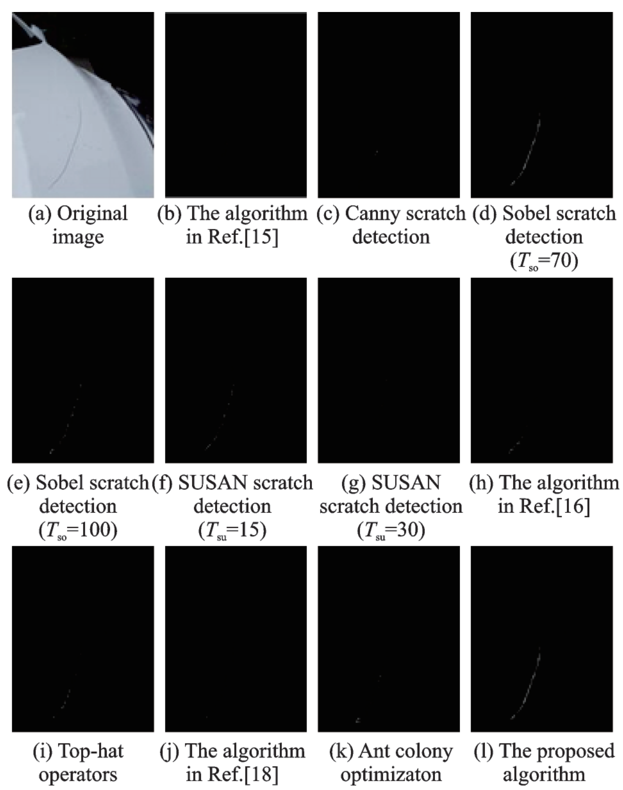
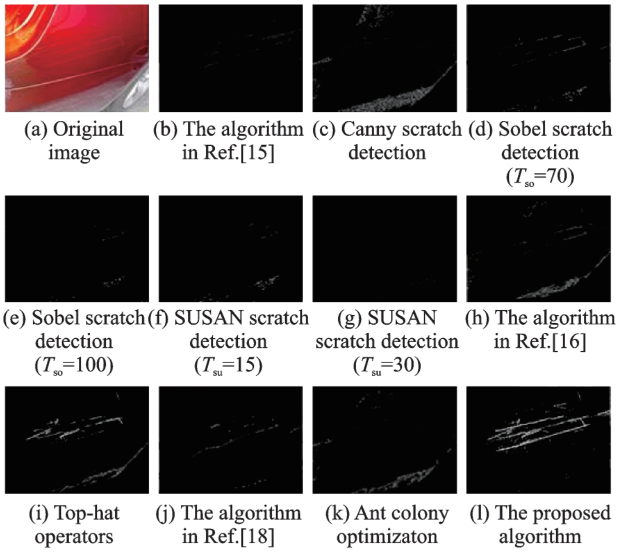



Fig.8 Scratch detection results of white car image



(a) Original image (b) The algorithm in Ref.[15] (c) Canny scratch detection (d) Sobel scratch detection ($T_{so}$=70)
(e) Sobel scratch detection ($T_{so}$=100) (f) SUSAN scratch detection ($T_{su}$=15) (g) SUSAN scratch detection ($T_{su}$=30) (h) The algorithm in Ref.[16]
(i) Top-hat operators (j) The algorithm in Ref.[18] (k) Ant colony optimizaton (l) The proposed algorithm

Fig.9 Scratch detection results of red car image

1 and Table 2.

It can be seen from the gray image of Fig.8 that because the white car parts of the image edge and background gray level difference are relatively small, and the gray value of similar pixels is converted to the same value in the Canny operator for converting the image to binary image process, the part fails to detect the detail of the edge. If the Sobel operator and the traditional SUSAN operator are used to detect the edge of gray image, the gray similar image cannot detect the edge. The proposed algorithm not only uses the gray information of the image, but also uses the chromaticity information of the image, so it can detect the edge of the image with similar brightness and different chromaticity.

From the detection results of Fig.9, we can see that the Canny algorithm is easy to detect false edges. In the edge detection process of Sobel algorithm and traditional SUSAN algorithm, if the threshold is too large, it is easy to lose information, and if the threshold is small, the edge detection is relatively rough. It can be seen that the choice of threshold affects the result of edge detection to a great extent. Too small threshold is easy to cause non-edge error detected as edge, and too large threshold is easy to

**Table 1 Performance comparison of white car using different algorithms**

| Parameter | Algorithm in Ref.[15] | Canny | Sobel ($T_{so}$=70) | Sobel ($T_{so}$=100) | SUSAN ($T_{su}$=15) | SUSAN ($T_{su}$=30) |
|---|---|---|---|---|---|---|
| Run time/s | 10.58 | 6.14 | 8.66 | 8.16 | 10.39 | 10.37 |
| Length of effective scratch/pixel | 1 806 | 617 | 1 966 | 1 900 | 1 985 | 1 953 |
| Undetected rate/% | 6.5 | 27.5 | 12.5 | 15 | 7.5 | 9 |

| Parameter | Algorithm in Ref.[16] | Top-hat operator | Algorithm in Ref.[18] | Ant colony | The proposed algorithm |
|---|---|---|---|---|---|
| Run time/s | 11.31 | 8.37 | 8.25 | 9.53 | 9.61 |
| Length of effective scratch/pixel | 1 806 | 1 556 | 2 007 | 1 778 | 2 135 |
| Undetected rate/% | 8.5 | 23.5 | 16.5 | 21.5 | 0.5 |

**Table 2 Performance comparison of red car using different algorithms**

| Parameter | Algorithm in Ref.[15] | Canny | Sobel ($T_{so}$=70) | Sobel ($T_{so}$=100) | SUSAN ($T_{su}$=15) | SUSAN ($T_{su}$=30) |
|---|---|---|---|---|---|---|
| Run time/s | 92.86 | 58.26 | 60.56 | 60.51 | 88.11 | 88.45 |
| Length of effective scratch/pixel | 11 075 | 7 594 | 9 556 | 7 531 | 10 000 | 9 746 |
| Undetected rate/% | 13.5 | 40 | 24.5 | 41.5 | 21 | 23 |

| Parameter | Algorithm in Ref.[16] | Top-hat operators | Algorithm in Ref.[18] | Ant colony | The proposed algorithm |
|---|---|---|---|---|---|
| Run time/s | 82.54 | 82.70 | 63.16 | 94.35 | 86.88 |
| Length of effective scratch/pixel | 10 063 | 8 923 | 8 544 | 8 544 | 12 026 |
| Undetected rate/% | 20.5 | 29.5 | 32.5 | 32.5 | 0.5 |

cause the loss of valid edge information. In this paper, the proposed algorithm converts the RGB space image into the uniform color space CIELab. It makes use of gray and chrominance information effectively. The appropriate threshold is selected according to the NBS unit and the color difference perception scale. For different color images, the edge information can be detected very well, and is more in line with human visual perception characteristics.

Table 1 and Table 2 clearly show that the algorithm in this paper does not change much in the speed of white body scratch detection, but it much higher than other algorithms in red body scratch detection. The algorithm in Ref.[15] has poor effect on color car scratch detection. Canny algorithm for shallow scratches almost fails to detect. Sobel algorithm also loses a lot of scratch information. If the scratches are shallower, the Sobel algorithm cannot detect them. The SUSAN algorithm has obvious improvement in body scratch detection, but still has the problem of missed detection.

In summary, the proposed algorithm can detect scratches on the surface of car body with higher detection efficiency and lower the detection rate. The algorithm in Ref.[16] is incomplete or unclear in edge. Top-hat operators cannot get effective edges. The algorithm in Ref.[18] causes more false detection. Ant colony optimization algorithm is ineffective in detecting scratches on car surfaces.

## 4 Conclusions

Car surface scratches are described as the positions of brightness information and chromaticity information occurring in a certain direction in CIELab space. Traditional edge detection uses gray image edge detection of color image, so it needs to be converted to grayscale images to achieve edge detection. However, gray information contains only 90% of structure information of the color image, so some edges cannot be detected, which leads to a high rate of missed detection in scratch detection of cars. Traditional SUSAN edge detection is based on gray image, and does not provide directional detection, which is easy to cause edge information loss. This paper proposes a directional color edge detection algorithm based on CIELab uniform color space. Firstly, the color difference between the pixels in the template and the central pixels of the template core is calculated. Then we need to determine whether the central pixel belongs to the USAN region, and use the directional template to determine the direction feature of the edge for filling the pixel defect along the direction. The size of the USAN region is calculated. Finally, the kernel pixel is defined as the edge point by comparing with a threshold. The experimental results show that the proposed algorithm can make full use of the chromaticity information, the brightness information of color images, and the directional characteristics of the edge. Furthermore, the edges and scratches of car images can be detected quickly and effectively, and the missing detection can be reduced.

However, the problem of edge detection cannot be realized when the background of the algorithm is not obvious and the color difference between the car bodies is not obvious in the paper, which will be improved in the next stage.

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