Road Detection Algorithm of Integrating Region and Edge Information

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ABSTRACT
In the unstructured environment-the road of cable tunnel, image processing is used to detect and extract the road information, which is used for the autonomous navigation system of the cable tunnel robot. Firstly, the adaptive median filter is used to smooth the road image acquisition. Then apply the Otsu method in the R component image of RGB color space to achieve the road area segmentation. According to the characteristic of the segmentation image, the mathematical morphology is used for further processing. For road edge detection algorithm, we choose Canny algorithm of accurate positioning and strong anti-interference ability. In order to achieve self-adaptive algorithm, the Otsu algorithm is applied to the threshold selection in Canny operator. Combining with the advantages of methods above, a new method of road boundary detection is proposed, which is based on the fusion of regional and edge information. The experimental results show that the algorithm can get smooth and accurate road edge.

Keywords
Region segmentation, mathematical morphology, self-adaption edge, detection, fusion algorithm

1. INTRODUCTION
Visual navigation is one of the important technologies and research focuses in the research field of intelligent mobile robot [1]. Detection and extraction of road guide line is a prerequisite for visual navigation and autonomous walking. Compared with the structured road, unstructured road has a certain complexity and diversity and the road scene is random. So at present, for this type of road there is not a strong adaptable detection algorithm. Generally, road detection algorithm is based on region segmentation or edge detection. Region segmentation is generally based on the global image feature.

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It can segment the background region and the target region, but the edge position is not very accurate [2-5]. Edge detection is generally based on the local characteristics of the image, which can get a more accurate edge location, but often also detected a lot of redundant edges [6,7]. In this paper, based on road environment of cable tunnel, we study the region segmentation and edge detection, and combine the advantages of the two methods to propose a new road detection algorithm of integrating region and edge information. The algorithm can obtain better road boundary and can be applied to other similar unstructured road environment, which has a certain theoretical significance and application value [8-11].

2. IMAGE PREPROCESSING
Median filter is a nonlinear filter, which is better for the treatment of random noise and can maintain the original clear contour of the image while filtering out the image noise. But when the filter template is not appropriate or too larger, the image of the details will be erased and appear edge thinning phenomena. In order to get better denoising effect and edge details, this paper uses adaptive median filter for image enhancement. Suppose S_{xy} as the template window size, of which the center pixel point is at (x, y). Several variables are defined: the minimum value of the pixel in the template window is $z_{\min} = \min(S_{xy})$, the maximum value of the pixel in the template window is $z_{\max} = \max(S_{xy})$, the median value of pixels in the template window is $z_{\mathrm{med}} = med(S_{xy})$, pixel value at (x, y) is z_{xy}, $S_{\max}$ indicates the maximum value allowed by S_{xy}. The implementation of adaptive median filtering is as follows:

Step A: $A_1 = z_{med} - z_{\min}$, $A_2 = z_{med} - z_{\max}$, if $A_1 > 0$ and $A_2 < 0$, then execute step B, otherwise, increase S_{xy}. If the template size $S_{\mathrm{xy}} \le S_{\max}$, then return to the execute step A, otherwise, output value z_{xy}.

Step B: $B_1 = z_{\mathrm{xy}} - z_{\min}$, $B_2 = z_{\mathrm{xy}} - z_{\max}$, if $B_1 > 0$ and $B_2 < 0$, output z_{xy}, otherwise, output z_{med}.

Step A and B are used to determine whether the z_{med} and z_{xy} are a pulse noise. If they are not impulsive noise, in order to avoid unnecessary details loss, then the algorithm outputs the current pixel value, otherwise output neighborhood median.


(a) adaptive median filtering


(b) 7 x 7 median filter


(c) 7 x 7 mean filter

Figure 1. Filtering effect of different algorithms

The results show that the whole image blurred after mean filtering. After the standard median filter, the random noise is removed, but the edge thinning phenomenon occurs and the edge details are erased. Adaptive median filter can not only remove the noise but also preserve the edge details by selecting template size automatically and using the original pixel value in the non impulsive noise.

3. ROAD REGION SEGMENTATION

3.1 Segmentation Based on R Component

By comparing the segmentation results of Otsu method, the maximum entropy threshold method and region growing method, the Otsu method is used to segment the road area.

Suppose a image has L gray levels $[0, L-1]$, there are n_i pixels belonging to gray level i. So the pixels number of the entire image is $N = \sum_{i=0}^{L-1} n_i$. The probability of each gray level is $p_i = \frac{n_i}{N}$. For p_i, there is $\sum_{i=0}^{L-1} p_i = 1$.

Use threshold T to divide the pixels in the image into two categories C_0 and C_1. Gray levels within $[0, T-1]$ belong to C_0, and gray levels within $[T, L-1]$ belong to C_1, then the probability of regional C_0 and C_1 are respectively $P_0 = \sum_{i=0}^{T-1} p_i$ and $P_1 = \sum_{i=T}^{L-1} p_i = 1 - P_0$. The average gray values of C_0 and C_1 are $\mu_0 = \frac{1}{P_0} \sum_{i=0}^{T-1} i p_i = \frac{u(T)}{P_0}$ and $\mu_1 = \frac{1}{P_1} \sum_{i=T}^{L-1} i p_i = \frac{\mu - \mu(T)}{1 - P_0}$. The average gray of the entire image :

$$\mu = \sum_{i=0}^{L-1} i p_i = \sum_{i=0}^{T-1} i p_i + \sum_{i=T}^{L-1} i p_i = P_0 \mu_0 + P_1 \mu_1 .$$

When the threshold value is T, the inter class variance is $\sigma^2(T) = P_0(\mu_0 - \mu)^2 + P_1(\mu_1 - \mu)^2 = P_0 P_1 (\mu_0 - \mu_1)^2$.

The range of T is $[0, L-1]$. When $\sigma^2(T)$ takes the maximum value, T is the threshold of Otsu segmentation.

If the road grayscale image is directly applied for OTSU threshold segmentation, the segmentation effect at the road boundary is not very good and it will produce some redundant blocks, which has an impact on the fusion algorithm back. Through the road color characteristics and experimental comparison, if selecting the R component of the RGB color space to conduct the threshold segmentation, we can get the ideal road segmentation map. The effect images are shown as subgraph (a), (b), (d) and (e) of figure 2.

3.2 Mathematical Morphological Processing

Because of the existence of noise, the road segmentation images are generally not ideal. Some small holes or cracks are scattered in the target area, and some small burr are scattered on the background area. Region segmentation map can not be directly used to extract the road boundary line, so it is necessary to optimize it. Therefore mathematical morphology can be used to deal with these disturbances.

Mathematical morphology lets the structure elements to traverse all the pixels and conducts logical operation with the surrounding neighborhood pixels. Its basic operations include expansion, corrosion, open operation and close operation.

Assuming that A and B are collections of Z^2, B is a structural element, then:

Corrosion is defined as $A \Theta B = \{ z | (B)_Z \subseteq A \}$

Expansion is defined as $A \oplus B = \{ z | (\hat{B})_Z \cap A \neq \varnothing \}$

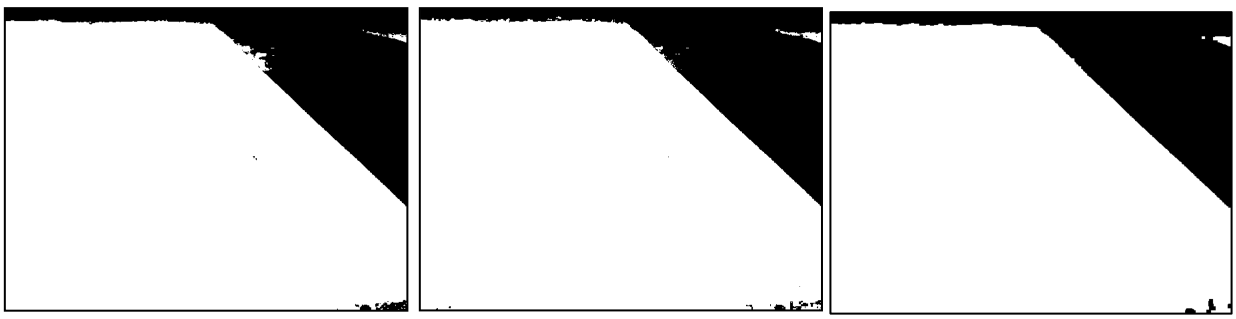
Open operation is defined as $A \circ B = (A \Theta B) \oplus B$

Close operation is defined as $A \bullet B = (A \oplus B) \Theta B$

Open operation is firstly use the structure element B to apply corrosion operation on the original image A , and then use the structure element B to apply expansion operation on corrosion results. Open operation is used to disconnect the narrow connection and eliminate the thorns. Close operation is firstly use the structure element B to apply expansion operation on the original image A , and then use the structure element B to apply corrosion operation on expansion results. Close operation is used to bridge the narrow gap and fill small holes and holes.

Through the analysis of road image region segmentation map, it is discovered that road region contains some noise holes and slits, background region contains some redundancy in the burr and the border of the road is not very smooth. In order to get the ideal road segment map, we must eliminate the small burr and close the small holes and cracks. In this paper, a morphological processing algorithms is put forward combing open operation and close operation, in which the structure element in the open operation is smaller than the structure element in the closed operation. Experimental results show that the use of an open operation and then a closed operation can remove the small noise points and burr and fill the cracks and noise holes well. The effect charts are shown as subgraph (c) and (f) of figure 3.

(a) segmentation effect of gray image. (b) segmentation effect of R component. (c) Morphological processing of fig(b).



(d) segmentation effect of gray image. (e) segmentation effect of R component. (f) Morphological processing of fig(e).

Figure 2. Region segmentation and morphological processing

4. ROAD EDGE DETECTION

4.1 Canny Edge Detection

Canny operator can accurately locate the edge while suppressing noise better. Compared with other edge detection algorithms, it reduces the sensitivity to noise, and improves the sensitivity of the edge.

Canny operator is based on three criteria:

(1) Signal to noise ratio is high and the margin error rate is low, so detected edges are generally real edges.

(2) Positioning accuracy is high, the detected edges are very close to the real edge centers.

(3) It is with single edge detection. For the real edge point, only return a value.

The implementation procedure of Canny operator is as follows.

a) Use Gauss smoothing filter to denoise

$$G(\mathrm{x},y)=\frac{1}{2\pi\sigma^2}\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)$$

$$\mathrm{g}(x,y)=f(x,y)*G(x,y)$$

σ is a Gauss filter parameter, which determines the image denoising effect. σ generally need to be determined according to experiment.

b) Calculation of gradient magnitude and direction

Canny algorithm uses the first order finite difference to calculate the gradient magnitude and direction of each pixel in the image, so that the gradient histogram of the image can be obtained. Differential in the direction of X and Y at (x,y) are respectively $G_x(x,y)$ and $G_y(x,y)$.

$$G_x(x,y)=\left(I(x,y+1)-I(x,y)+I(x+1,y+1)-I(x+1,y)\right)/2$$

$$G_y(x,y)=\left(I(x+1,y)-I(x,y)+I(x+1,y+1)-I(x,y+1)\right)/2$$

The gradient magnitude and direction at (x,y) are respectively:

$$G(\mathrm{x},y)=\sqrt{G_x^2(\mathrm{x},y)+G_y^2(\mathrm{x},y)}$$

$$\theta(\mathrm{x},y)=\arctan\left(\frac{G_x(\mathrm{x},y)}{G_y(\mathrm{x},y)}\right)$$

c) Non maximum suppression

After the gradient magnitude and direction are calculated at all pixel points, the non maximum gradient in the neighborhood is set to zero and the pixel points with the maximum gradient value are preserved, which can obtain a relative thin edge. In the same gradient direction, if the value of the gradient is smaller than the gradient of the adjacent point, then make M=0. Otherwise, it will be considered as the candidate edge points.

d) Detect and connect edges

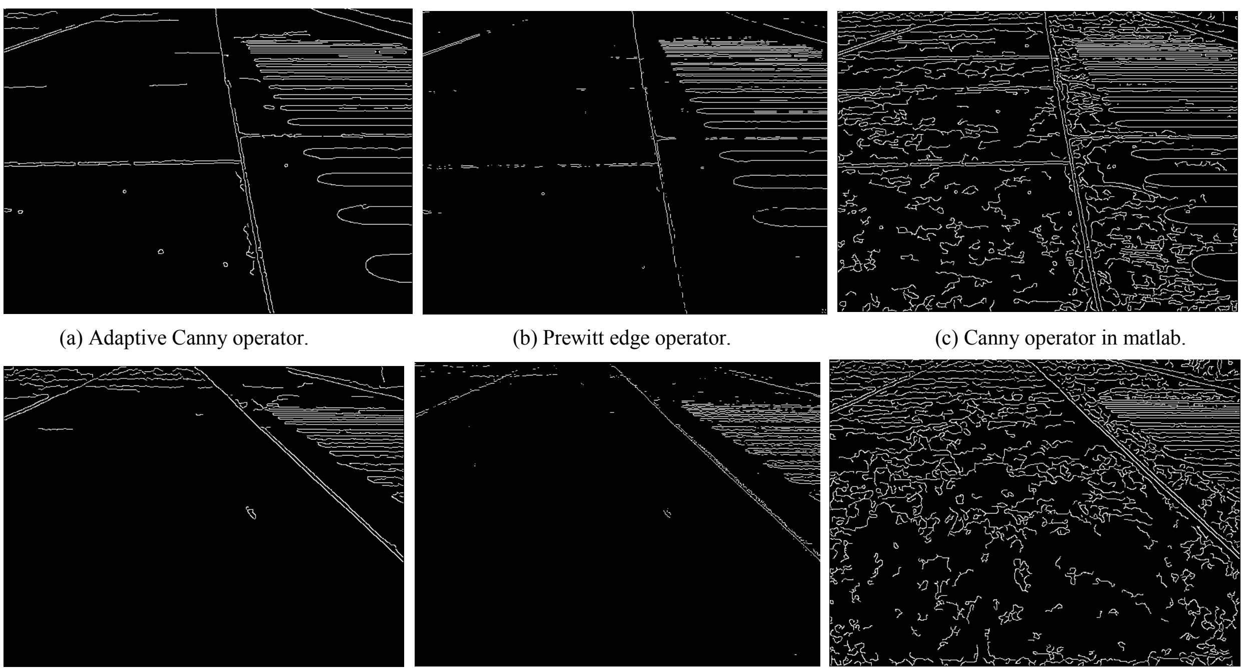
Finally, the Canny operator uses a hysteresis threshold (i.e., high threshold and low threshold). Start scanning all pixel points: If the gradient amplitude at a certain pixel point is greater than the high threshold, then consider these points as edge points; If the gradient amplitude at a certain pixel point is smaller than the low threshold, then consider these points as non edge points; If the gradient amplitude at a certain pixel point is between the high and low threshold, then we need to add a constraint: if the pixel point is in the 8 neighborhood of the pixel whose gradient larger than the high threshold, it will be regarded as the edge point, or it will be discarded.

4.2 Adaptive Canny Edge Detection

The first parameter of Canny operator is Gauss filter parameter, which is related to the effect of the image filter. If the Sigma value is too small, the image denoising effect is not good and if too large, the image edge details are blurred. According to the experiment, we take sigma 0.2 .

The two other parameters of Canny operator are the high threshold and low threshold, which are generally set up according to human experience in advance. Gradient distribution of different road images is not the same, so the setting of the threshold value of each frame image is not the same. If the high threshold is set too high, then the part of the road edge will not be detected, and the detected edges may appear intermittent situation. If the high threshold is set too low, it will detect a lot of interference edge or not related edge. In addition, when the robot is in motion, the image is changing in a frame by frame. If two fixed threshold for edge detection is set, it can not meet all the road images. Therefore, it is necessary to design a method to automatically obtain the high and low thresholds value according to the road image information of the current frame. The gradient magnitude image is expressed by gradient histogram, it is found that the gradient histogram is in characteristics of Shuangfeng. In addition, high and low threshold of the Canny operator are essentially a kind of gradient threshold.

In this paper, in order to make the traditional Canny algorithm adaptive, the Otsu algorithm is used to calculate an optimal threshold, and the threshold value is used as the high threshold value of the Canny operator. The low threshold value is determined by the high threshold value $T_l = (0.4 \sim 0.6)T_h$. In this paper, take $T_l = 0.4T_h$.



(a) Adaptive Canny operator. (b) Prewitt edge operator. (c) Canny operator in matlab.

(d) Adaptive Canny operator. (e) Prewitt edge operator. (f) Canny operator in matlab.

Figure 3. Edge detection of road image

5. DETECTION ALGORITHM OF INTEGRATING REGION AND EDGE INFORMATION

Although the region segmentation can separate the target road and the background area, the location of the road boundary line is not accurate enough. Although edge detection can accurately detect the edge of the road, but at the same time, it also detected a lot of irrelevant edges. If we use the Hough transform to extract the navigation line directly in the edge detection image, the result can be of great uncertainty, so we must eliminate the interference from the irrelevant edges. According to threshold segmentation and Canny detection results above, it can be found that the two methods have complementary characteristics. Therefore, based on the complementary characteristics of the two methods, this paper proposes a road detection algorithm of integrating region and edge information. Making use of the characteristics that region segmentation can separate the road and non road region, filter out the interference edge map and preserve the single edge of target and background junction.

The specific fusion algorithm is:

a) Set the boundary trusted region

The road boundary is usually located in the target and the background area in the region of two values. In the region segmentation binary diagram, start to scan line by line. When the pixel point I(j,i) scanned is in the change of black and white, it is considered to be the possible boundary point and the pixel point is extended M pixels as the trusted region of the road boundary points. In this paper, M is set to 10. After the search is completed, N trusted areas are produced .

b) Locate the road boundary in the trusted region

In the edge image, scan pixels in the trusted zone one by one. If first scanning the edge points in the first K trusted region, they will be considered as the boundary points. And then continue to search in the first K+1 trusted area, if there is at least one edge point in this range, then the edge points are judged as follows: If there is a point in the next 10 neighborhoods of the point which is marked as the point of the road boundary, the point is marked as the point of the road boundary; the next 10 neighborhoods image is as shown in Figure 5. If these edge points are not in the next 10 neighborhood of a point which is marked as the point of the road boundary, all points in the range will be recorded as the boundary points. According to this algorithm, search each trusted region one by one and mark out all the road boundary points so that we can get the required single edge of the road boundary.

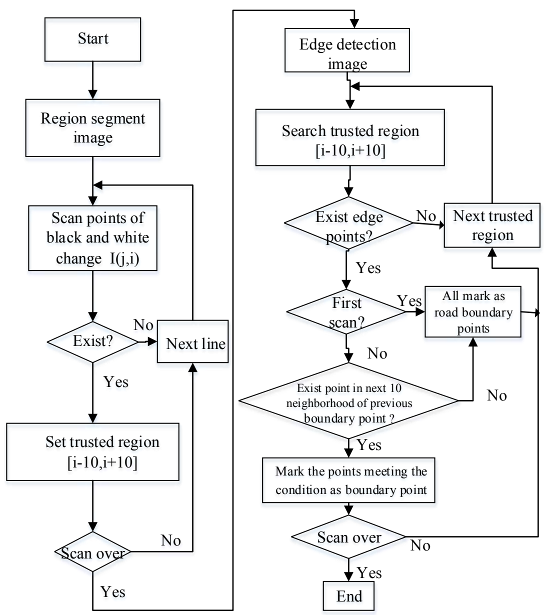
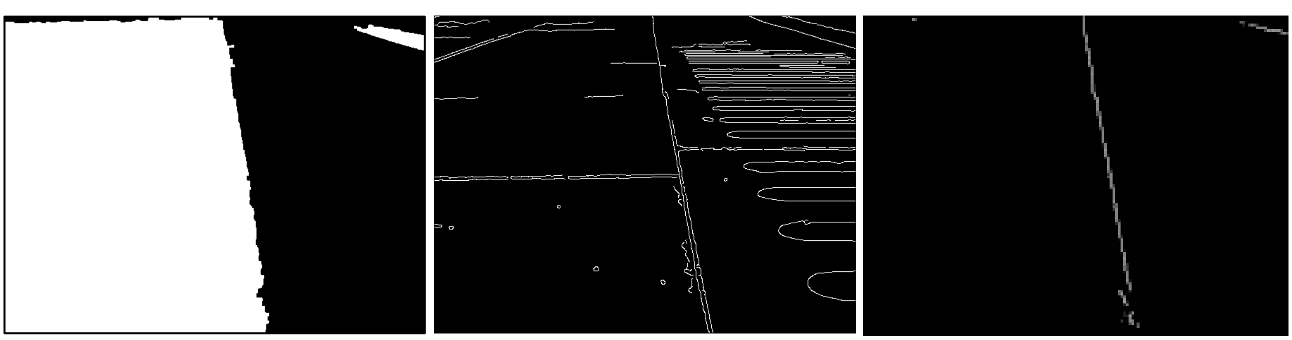


Figure 4. Flow chart of fusion algorithm

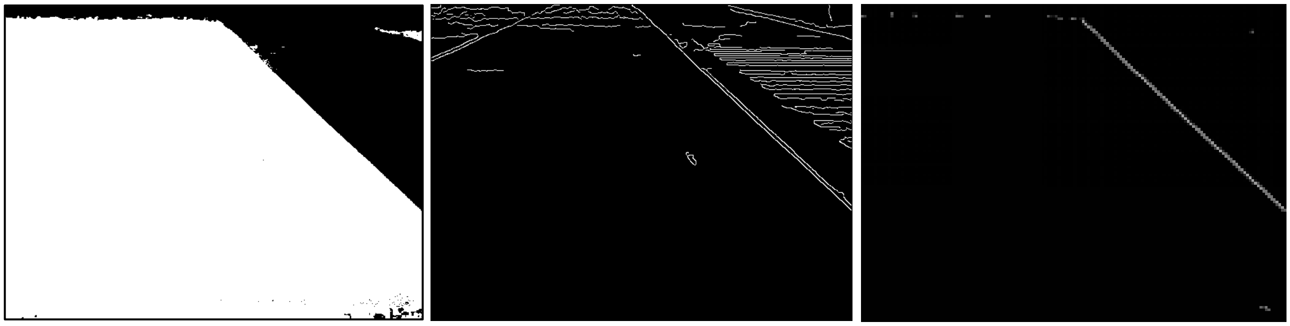
		(i,j)		
(i+1,j-2)	(i+1,j-1)	(i+1,j)	(i+1,j+1)	(i+1,j+2)
(i+2,j-2)	(i+2,j-1)	(i+2,j)	(i+2,j+1)	(i+2,j+2)

Figure 5. 10 neighborhood templates in the fusion algorithm

The road boundary in a image is generally a single edge. In the foreground may appear false edge and double edge and burr interference in prospective area. In close range it may appear false edge, double edge and burr interference. In the algorithm step (2) above, if don't make a judgment and all the edges in the trusted area are considered as boundaries, the result may be a road boundary line of double edge. The fusion algorithm in this paper makes full use of the characteristics and continuity of the road boundary, and gets the ideal single road boundary. This algorithm makes use of the complementary characteristics between the region segmentation and edge detection and can detect the edge of the road accurately.



(a) Road area segmentation map. (b) Adaptive Canny edge detection (c) Road boundary after fusion.



(d) Road area segmentation map. (e) Adaptive Canny edge detection. (f) Road boundary after fusion

Figure 6. Road boundary detection of Integrating region and edge

6. CONCLUSION

Road detection algorithm is an important part of visual navigation, the accuracy of the road boundary line determines the performance of the whole system. In this paper, take the cable tunnel road as the experimental object, study and analyze the results of region segmentation and edge detection, and put forward a road boundary detection of integrating region and edge. The experimental results show that the fusion algorithm can detect the road boundary line with accurate and smooth position.

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