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Autonomous navigation method for substation inspection robot based on travelling deviation

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Abstract. A new method of edge detection is proposed in substation environment, which can realize the autonomous navigation of the substation inspection robot. First of all, the road image and information are obtained by using an image acquisition device. Secondly, the noise in the region of interest which is selected in the road image, is removed with the digital image processing algorithm, the road edge is extracted by Canny operator, and the road boundaries are extracted by Hough transform. Finally, the distance between the robot and the left and the right boundaries is calculated, and the travelling distance is obtained. The robot's walking route is controlled according to the travel deviation and the preset threshold. Experimental results show that the proposed method can detect the road area in real time, and the algorithm has high accuracy and stable performance.

1 Introduction

Smart Grid is thought to be the intending direction of the power grid，that is to say, lots of new helpful techniques have been applied in power generation, power transmission, power distribution, electricity and etc, which to realize automation, integration, centralization and intellectualization of power network management [1]. As a hub, the substation must be regularly checked to ensure safe operation, so it is very important to detect the running state of substation equipment by using robots in unattended environment [2].

At present, the robot mainly uses the way of magnetic navigation for inspecting substation equipment, the magnetic stripe needed to be laid in the ground which will increase the cost of construction [3]. Robot vision navigation determines the position relationship between the robot and the navigation line by using foreground vision to capture road images in real time and image processing techniques to identify the route, and then the inspection task is realized through the bottom motion control to guide robot walking. This visual navigation system enhances the system flexibility and reduces the cost.

In this paper, a method of autonomous navigation based on travel deviation is proposed for substation inspection robot. The road edge is obtained according to the image processing technology in the substation environment, and then the distance between the robot and the road edge is calculated. And then，the distance information is used to control the robot.

2 Road detection

The road edge is the dividing line between the road and non road. Road recognition is a process of segmentation and merging, by which can be divided into road and non road4], so the road area is correctly detected in the image. The road area in the image has the following characteristics:

(1) The brightness of the road (no shadows and no water) in the image is greater than the brightness of the non road;

(2) When the robot moves forward, the road is always in front of robot;

(3) The road has a certain width and area;

(4) Because the road area is below the horizon, 60% of image is processed in algorithm.

In the substation, the road is mainly structured road, its edges are clear and rules, as shown in figure 1. As can be seen from the figure, there is a clear boundary between the cover plate for cable trench and the surrounding gravels, and the other edge of the road has remarkable characteristics such as the curb. Therefore, it is necessary to make full use of the characteristics of the road area to detect the road area, and there is no need to draw the road boundary or guide line.

(a) road in equipment area (b) road of cable trench cover plate

Figure 1: Roads in the substation

3 Edge detection

There has the perspective phenomenon and the interference of the substation equipment in the road image, so the ROI area of the road image is selected before the edge detection. It can not only reduce the amount of calculation but also reduce the influence of noise in the ROI area, and improve the accuracy of the algorithm. Because the road area is mainly the lower part of the image, the lower part of the image is selected as the ROI region.

3.1 Canny edge detection

Canny edge detection operator is developed by John F. Canny in 1986 which is a multi-level edge detection algorithm [5]. The goal of Canny is to find an optimal edge detection algorithm, and the optimal edge detection means as follows:

(1) The algorithm can identify the actual edge of the image as much as possible.

(2) The identified edge was most likely to the actual edge of the image.

(3) Edges in the image can be identified only once, and the image noise that may exist should not be identified as edges.

Canny edge detection algorithm [6]:

Step1: using Gauss filter to smooth the image;

Step2: uses finite difference of first order partial derivative to calculate the magnitude and direction of the gradient;

Step3: non maximum suppression for gradient amplitude;

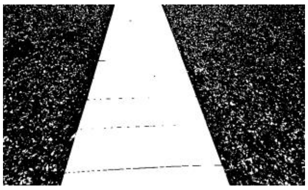
Step4: using dual threshold algorithm to detect and connect edges.

3.2 Mathematical morphology

Mathematical morphology is a subject of image analysis based on Glen and topology, which is the basic theory of image processing. In 1964, mathematical morphology is introduced into the field of image processing by Matheron and Serra based on research results of integral geometry. The application of mathematical morphology can simplify the image data, maintain their basic shape characteristics, and remove the irrelevant structure. It can be used to solve the problem of noise suppression, feature extraction, edge detection, image segmentation, shape recognition, texture analysis, image restoration and reconstruction, and image compression [7]. There are 4 basic operations of mathematical morphology: dilation, erosion, open and closed operation [8].

One of the simplest applications of the dilation is the bridging of cracks, that is to say, the dilation will increase or coarse the target object in the image. The erosion operation can remove some parts of the image, which means the image is reduced or refined, it is a filtering operation and removes the image details from the image less than the structuring element.

Due to the gap between the cable trench cover plate, the road area will be broken after the two value of the road area. In order to be smooth and continuous, the dilation operation is first used in the treatment process to connect gap, and then the erosion operation is used to remove the noise and reduce the expansion of the road area. Figure 2 is the result of the process for the cable trench cover pavement.



(a) gray scale image (b) binary image

(c) dilation image (d) erosion image

Figure 2：Morphological image processing

3.3 Hough transformation

Using Hough transform to detect line is an important part of image analysis and computer vision. And the advantages of Hough transform is that it has better anti noise performance and can connect collinear short straight line [9]. The basic idea of Hough transform is to use duality of point and line, namely the collinear points in image space corresponds to intersection line in the parameter space.

Its essence is to find all pixels of line for detecting line in the image. When the slope of the line exists, all the collinear points (x, y) can use the equation (1), where k is the slope, b is the intercept.

$$y = kx + b \tag{1}$$

4 Travel deviation

It is a non-contact, simple and reliable method to obtain the traffic information through the video image of the road. It is widely accepted and recognized for driving safety assistance system [10]. The core of travel deviation detection system based on video is lane detection. Namely, the boundary is used as the basis of road recognition based on the linear lane model.

The deviation can be used as a measure of robot off road while driving [11]. In order to reduce the error caused by camera angles (the direction of the robot forward), the current position of the robot can be determined by calculating the ratio of distance from viewpoint (the center of lower image) to left edge and right edge to the current lane. The distance from the robot to the right of the current lane is shown in the equation (2).

$$d = d_2 \times \frac{w}{d_1 + d_2} \tag{2}$$

Among them, d_1 is the distance from viewpoint to the left boundary (pixels), d_2 is the distance from viewpoint to the right boundary (pixels), w is lane width (m).

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5 Experimental results and analysis

According to the road conditions to select the ROI area, after preprocessing the ROI road image, the boundary of the road is obtained by edge detection. Algorithm processing flow chart is shown in Figure 3. Road edge detection and detection results, as shown in figure 4 and figure 5. As can be seen from the test results, the method has good effect in this paper, and can accurately detect the edge of the road, and the shadow also has a very good robustness, as shown in figure 6.

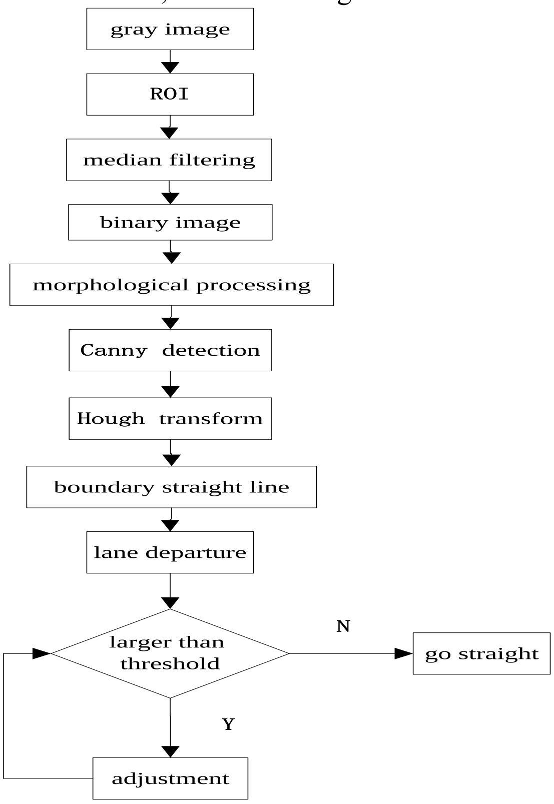
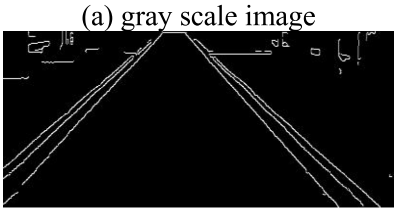
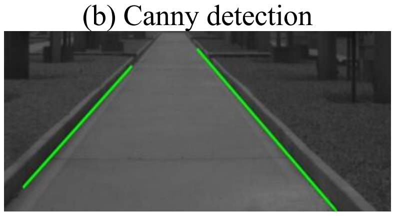


Figure 3: Algorithm flow chart

(a) gray scale image



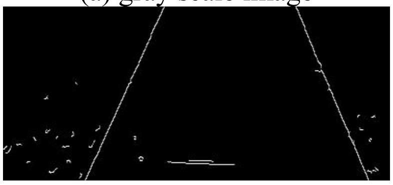
(b) Canny detection



(c) boundary straight line

Figure 4: Road image

(a) gray scale image



(b) Canny detection

(c) boundary straight line

Figure 5: Road image of cable

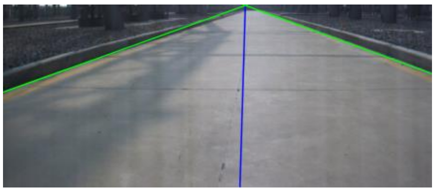


Figure 6: Recognition results

The results of the experiment are listed in the 100 frame images. The slope of the left and right edge boundary line are calculated, and the distance from the robot to the left and right of the current lane are calculated.

Figure 7 shows the variation of the slope of the edge boundary and the mean of the slope. After statistical data, the mean value of the slope for the left edge is: ml=-0.3576, the variance is vl=0.0073; the mean value of the right edge slope is mr=0.3896, the variance is vr=0.0088. Test results show that the inclination of the boundary line equation obtained by edge detection is a complementary relationship, that is, the left and right boundaries are two parallel straight lines, which can be a better response to the road.

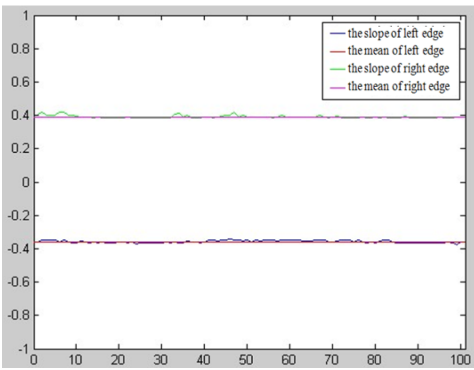


Figure 7: The slope statistics of left and right edge

Figure 8 shows the distance from robot to the current lane and the mean statistics, the group of experimental data intercept 100 frame road images in the morning, where the road width is three meters. The mean value of the distance from robot to the left edge is: mdl=1.4464, the variance is: vdl=0.0264; the mean value of the distance from robot to the right edge is: mdr=1.5536, the variance is vdr=0.0264.

In figure 8 the statistical data reflect the stability of the robot during walking robot, the distance from robot to left boundary and right boundary is stable, which corresponds to the actual distance. Test data show that, in the process of robot walking, we can take the distance between the left and the right side of the road as a measure, and control the robot's walking way by comparing with the preset threshold.

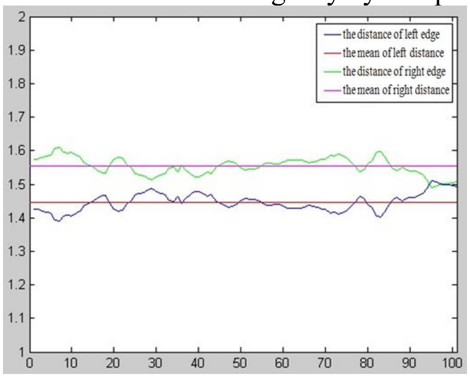


Figure 8: The statistics of travel distance

6 Conclusion

In this paper, we use the Hough transform to detect the edge of the road and get the edge linear equation by choosing the region of interest, filtering and other related processing. According to the linear equation of the road edge, the driving distance can be calculated for robot in the process of driving, the driving route of the robot can be adjusted by comparing the distance of travel distance and the preset threshold. The experimental results show that the algorithm has good robustness, and can be well under different conditions. The algorithm is simple, fast and accurate, which can satisfy the autonomous navigation of the substation inspection robot. The successful implementation of the algorithm enhances the automation and intelligent ability of the substation inspection robot, and promotes the process of the unattended substation.

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