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Rural Road Detection of Color Image in Complicated Environment

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Abstract

To realize rural road detection in complication environment, a method based on improved FCM (Fuzzy C-Means) and Hough transformation has been proposed. Firstly, the road image is transformed from RGB space into HIS space. Second, the initial clustering center is determined using climbing method looking for image saturation histogram peak in HIS color space and the road area is detected using improved FCM. Finally, after morphological image processing, road boundary is detected using Hough transformation. Experimental results show that the method presented in this paper has good ability to detect the road boundary. The method is robust and not influenced by shadow, water vestige, rainy days and other environmental factors.

Key words: *rural road; saturation; feature extraction; clustering algorithms; boundary detection; image analysis*

1. Introduction

Road detection is the premise of intelligent vehicle achieving autonomous navigation. Recently, with the widely research and application of agricultural machinery equipment, vehicle assistant driving and driver fatigue detection, road detection is becoming a hotspot gradually [1-4]. Usually, road can be divided into structured and unstructured road. Because structured road has obvious lane and boundary, the detection has made great progress. But unstructured road has no obvious lane and boundary, and is vulnerable to shadow and illumination changes, road detection is more different, which is at the research stage [5-7]. The methods of unstructured road detection can be divided into: based on road model [8], based on road feature [9-10] and based on neural network [11-12]. The method of based on road model contains three steps: assuming road has regular boundary; establishing lots of road model; finding appropriate road model based on image. This method is not influenced by environmental factors such as illumination and shadow, but it is not suitable for all road detection. The method of based on road features uses the differences at color and texture to realize road and non-road area. The method is sample, but has lower success rate. Road detection based on neural network is through training a large number of samples, using the learning feature of neural network for road detection. This method requires a lot of prior knowledge. Because actual road is too complex, the sample is not selected completely. Rural road belongs to the unstructured road which is also influenced by rural environment, so road detection is more difficult. In order to solve the problem, we propose a method based on improved FCM and Hough transformation. Firstly, the road image is transformed from RGB space into HIS space. Second, the initial clustering center is determined using climbing method looking for image saturation histogram peak in HIS color space and the road area is detected using improved FCM. Finally, after morphological image processing, road boundary is detected using Hough transformation.

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2. Image Space Transformation

Compared with other road, rural road is more complex for without clear road edge and sign. Using gray image to detect road area is not an easy work. For color image having more information, we detect road area based on color image [13].

The key of color image segmentation is the chosen of image space. In RGB color space, image is described with three components (R, G, B) which have higher correlation. So the result of road detection in RGB color space is not good. HIS space is close to human's perception of color. Brightness is separate with hue and saturation. H, I, S of road image are shown in Figure.1. We can conclude that in H an S space, the difference between road area and non-road area is not obvious which is influenced by illumination. In I space the difference is very obvious which is not influenced by illumination. Therefore, we will detect road area in I space.

(a) Road image (b) H (c) I (d) S

Figure 1. Road Image and HIS Components

2. FCM Road Segmentation

2.1. Fuzzy C-Means Algorithm

Fuzzy C-Means algorithm is an unsupervised statistical classification algorithm which is without any human intervention and accord with people's cognitive features [14]. So we will use FCM to detect road area.

Firstly, we should determine an initial clustering center according to the peak value of histogram. In the paper, we use the method of "climbing mountain" to find peak value. Compare the current point with surrounding neighborhood point, if the current point is the largest, it returns the current point as the histogram peak; otherwise, it takes the largest point of surrounding neighborhood as extreme value to find the largest point. Histogram peak should satisfy

$$P = (i, (H(i) > H(i-1) \,\&\, H(i) > H(i+1))) \quad (1)$$

Where P is the peak; $i = 0,1,\cdots,255$; $H(i)$ is the histogram of saturation.

To prevent trapping in local optimum, according to the actual situation of rural road, pixel distance of extreme value should be greater than a certain threshold and the corresponding pixels should be more than a certain number. Road image can be divided into road region and the road area, so we take two extreme value points.

And then we use the membership function to describe the distance between each pixel and the clustering center. According to the membership function, clustering usually can be divided into hard clustering and fuzzy clustering. In hard clustering, the membership degree of each pixel has only two possible values: 0 or 1. But in fuzzy clustering, all pixels belongs to one class and the membership value of each pixel is a value in [0,1]. Fuzzy C-Means is a kind of fuzzy clustering. Where n samples ($\{x_i, i = 1,2,\cdots,n\}$) are divided into c ambiguity sets. Each sample has the membership value μ_{ik} (it represents that i sample belong to the k class) and it finds each cluster center $v_i (i = 1,2,\cdots,c)$ in

order to minimize the loss function:

$$\min J_f = \sum_{i=1}^{c}\sum_{k=1}^{n} \mu_{ik}^m d_{ik}^2 \qquad (2)$$

Where m is a constant of fuzzy control; $d_{ik} = \|x_k - v_i\|$ is Euclidean distance between k sample and i cluster center.

According to previous analysis, the total membership value of each pixel is 1. That means

$$\sum_{i=1}^{c} \mu_{ik} = 1 \qquad (3)$$

And according to formula (2, 3), we take partial derivatives respect to v_i and μ_{ik}, and we can conclude the necessary condition of Fuzzy C-Means:

$$\mu_{ik} = \frac{1}{\sum_{j=1}^{c}\left(\frac{d_{ik}}{d_{jk}}\right)^{\frac{2}{m-1}}} \qquad (4)$$

$$v_i = \frac{\sum_{k=1}^{m}(\mu_{ik})^m x_k}{\sum_{k=1}^{n}(\mu_{ik})^m} \qquad (5)$$

The concrete calculation process of FCM is as follows:

Step 1 Determine the cluster number c, the largest number of iterations T, iterative error $\varepsilon > 0$, the initial cluster center $v_{i0}(i = 1,2,\cdots,c)$, $t = 1,2,\cdots,T$.

Step 2 Given: $d_{ik,t} = \|x_k - v_t\|$, if $d_{ik,t} = 0$, $\mu_{ik,t} = 1$ and when $j \neq i$, $\mu_{ik,t} = 1$; if $d_{ik,t} > 0$, $\mu_{ik,t} = \frac{1}{\sum_{j=1}^{c}\left(\frac{d_{ik}}{d_{jk}}\right)^{\frac{2}{m-1}}}$.

Step 3 Calculate $v_{t+1} = [v_{1,t+1}, v_{2,t+1}, \cdots, v_{c,t+1}]$, among them $v_{i,t+1} = \frac{\sum_{k=1}^{m}(\mu_{ik,t})^m x_k}{\sum_{k=1}^{n}(\mu_{ik,t})^m}$.

Step 4 If $\|v_{t+1} - v_t\| = \sum_{i=1}^{c}\|v_{i,t+1} - v_{i,t}\| \leq \varepsilon$, the iteration is end; otherwise calculate the next *t*.

2.2. Improved Fuzzy C-Means algorithm

The traditional FCM always need calculate the cluster center and membership function in every iteration process, so there will be more calculation. Rural road is often influenced by environmental factors so that it is difficult to determine the initial cluster center. To

solve the problems, we propose an improved Fuzzy C-Means algorithm.

In saturation image, the area of gray which has big changes focuses on the road boundaries and most area of road has similar gray level. So, each pixel can be replaced by average gray values in road area. This method can effectively reduce the environmental factors influence and also reduce some sample spaces.

Improved Fuzzy C-Means algorithm can be described as follows

Step 1 The saturation image is divided into N areas with the same size and FCM cluster is based on the average grey value of each area.

Step 2 To find the area with big gray change, we have defined area roughness C_n and average roughness C [15].

$$C_n = (\frac{1}{c}\sum_{i=0}^{c-1}\left\| x_i - \bar{x} \right\|^2)^{\frac{1}{2}},\ C = (\frac{1}{N}\sum_{n=0}^{N-1} C_n)$$

Where x_i is the *i*th gray value; $\bar{x}$ is the average gray value. If area gray value satisfies $C_n \geq \alpha \cdot C$, we think that the area is road boundary and background area. And then according to threshold array, the area is divided into M areas.

Step 3 the N+M-1 areas is calculated with FCM again until meet the condition.

The result of improved Fuzzy C-Means algorithm is shown in Figure 2. Road area and non-road area are separated well.

Figure 2. Result of Improved FCM

3. Road Boundary Detection

3.1. Morphologic Processing of Images

Morphological image processing is an important research area. The basic idea is to use some structural elements to measure and extract the corresponding shape in order to analyze and identify image. It has open and closed operations which are based on the inflation and corrosion.

Noise signal mainly contains massive and ribbon noise of edge area and local point noise, as Figure 2 shows. In order to eliminate the noise, we firstly eliminate the massive and ribbon noise of binary image and then use closed and open operation.

3.2. Road detection based on Hough Transform

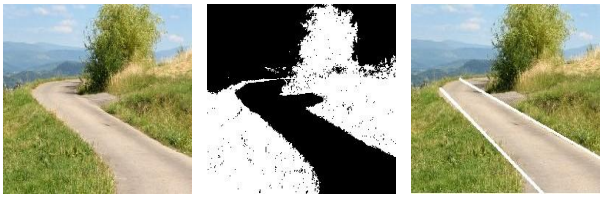
The result of FCM segmentation shows that road boundary can be approximated as a straight line. So we use the Hough transform to detect road boundary.

Hough transform is often used in the detection of simple shape, such as straight line and circle which has good robustness and anti-interference ability. The essence of Hough transform is a map of transforming image space into parameter space. The final result of road detection is shown in Figure 3.

Figure 3. Result of Road Area

4. Experiments and Analysis

In order to verify the feasibility of the proposed algorithm, we chose some rural road in different scenarios. The results are shown in Figure 4. Whether sand road, gravel road or asphalt road, road boundary can be identified very well.



(a) Sand road

(b) Gravel road

(c) Asphalt road

Figure 4. Detection of Three Kinds of Roads

Table 1 shows the results of three different rural roads detection. It is obvious that the detection rate of asphalt road boundary is the highest, higher in gravel road and high in sand road. The reason is that sand and gravel road have uneven road surface and are affected by illumination. Asphalt road has even road surface, but it also is affected by water vestige and road surface damage.

Table 1. Results of Three Kinds of Roads

Road	Total	Correct	Error	Accuracy
Sand	2000	1756	244	87.8%
Gravel	2000	1812	188	90.6%
Asphalt	2000	1950	50	97.5%

Figure.5 shows the result of road detection in different illumination. It is obvious that

the proposed algorithm has good robustness to illumination change.

(a) Dark morning

(b) Bright noon

Figure 5. Road Detection of Different Times

Figure 6 is the results of rural road detection in complex environment. Compared with the traditional FCM, improved FCM can distinguish the road region and non-road region better and it is not influenced by water vestige and illumination.

(a) Rain road (b) FCM detection (c) Improved FCM

(d) Muddy road (e) FCM detection (f) Improved FCM

Figure 6. Road Detection under Complicated Environment

Table 2 shows the times for two kinds of FCM. Improved FCM needs less time and has better real-time performance.

Table 2. Comparison of Processing Time (s)

Image	FCM	Improve FCM
Fig.6 (a)	7.662	0.539
Fig.6 (b)	6.326	0.485

Table 3 shows the result of the proposed algorithm compared with other algorithms. Neural network requires a lot of prior knowledge and needs more time. Road detection based on model depends on the established road model to much; Road detection based on feature is easily affected by environmental factors such as water vestige and illumination. Our proposed algorithm doesn't need prior knowledge and is not influenced by shadow, water vestige, rainy days and other environmental factors.

Table 3. Compared with other Algorithms

Algorithm	Prior knowledge	Influenced by environment	Calculation speed
Neural network	More	Weak	Slow
Based on model	More	Weak	Fast
Based on feature	Less	Strong	Fast
Proposed algorithm	No	Weak	Fast

5. Conclusions

We propose a method based on improved FCM and Hough transformation. Firstly, the road image is transformed from RGB space into HIS space. Second, the initial clustering center is determined using climbing method looking for image saturation histogram peak in HIS color space and the road area is detected using improved FCM. Finally, after morphological image processing, road boundary is detected using Hough transformation. The algorithm doesn't need prior knowledge and is not influenced by shadow, water vestige, rainy days and other environmental factors.

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