Pavement Image Segmentation Based on FCM Algorithm Using Neighborhood Information

Xinsong Wang, Guofeng Qin*

The CAD research center, Tongji University
4800 Caoan Road, Jiading District, Shanghai, China
*corresponding author, e-mail: timwong1234@163.com, gfqing@yahoo.com.cn*

Abstract
Standard FCM algorithm takes the pixel gray-scale information into account only, while ignoring the spatial location of pixels, so the standard FCM algorithm is sensitive to noise. This paper presents a pavement image segmentation algorithm based on FCM algorithm using neighborhood information. The presented algorithm introduces neighborhood information into membership function to improve the standard FCM algorithm. It can eliminate noise effectively and retain the boundary information. The experiments by synthetic images and real pavement images show that the presented algorithm in this paper performs more robust to noise than the standard FCM algorithm and retain the boundary information effectively.

Keywords: FCM algorithm; neighborhood information; membership; pavement image segmentation

1. Introduction
Image segmentation is a process to divide image into a number of specific sub-regions with unique properties and it play a key role in image analysis and pattern recognition[1-6]. Traditional image segmentation algorithms including histogram threshold method, feature space clustering, region based method, edge detection, fuzzy method, neural network method[7].

Fuzzy C-means algorithm(FCM) is an unsupervised clustering algorithm, with the optimization of objective function, membership degree is obtained for each sample point to all clustering centers. this in turn, sample segmentation will be achieved. Compares with hard C-means clustering algorithm, fuzzy C-means algorithm can retain the original image information more effectively, but standard fuzzy C-means algorithm does not take pixel spatial location information into account, so the standard fuzzy C-means algorithm is sensitive to noise.

In order to solve this problem, many researchers consider pixel spatial information into account, through modification of the standard FCM clustering algorithm membership function or objective function to make the image segmentation performance better than before. Literature [8] introduces median filter image to modify FCM objective function and has been successfully applied to the segmentation of MRI; Literature [9] introduces mean filter image to improve objective function of FCM algorithm, and this modified algorithm with mean filter is more robust to noise. However, regardless of median filter or mean filter, they did not make full use of the information of neighborhood pixels. This paper proposes an adaptive neighborhood information matrix, it can eliminate noise and retain the boundary information effectively. The experiments by synthetic images and real pavement images show that the presented algorithm is more robust to noise than the standard FCM algorithm and can retain the boundary information more effectively.

2. Standard FCM [10],[11]
2.1. Basic Thought Of FCM
The basic thought of FCM algorithm is to divide a dataset \( X = (X_1, \ldots, X_n) \in R^{n \times p} \) with \( n \) samples and \( p \) dimension into \( c \) classes. By means of iteration to find the optimal clustering centers and membership function with which to make objective function minimized. So as to determine each sample belongs to which clustering center.
2.2. Implementation Of FCM Algorithm

2.2.1. Main Parameters And Functions Of FCM Algorithm

(1) $\bar{U}$: a fuzzy C-division of input space.
(2) $n$: number of data sample.
(3) $c$: number of clusters.
(4) $m$: fuzzy exponent, $1 \leq m \leq \infty$, in general, $m = 2$.
(5) $d_{i,k} = \|x_i - v_k\|_2^2$: distance between sample point $x_i$ and clustering center $v_k$.
(6) $u_{i,k}$: membership function of sample point $x_i$ to clustering center $v_k$, $u_{i,k} \in [0,1]$, $1 \leq i \leq n$, $1 \leq k \leq c$.
(7) $V$: initial clustering centers.
(8) $\xi$: termination condition of the iteration.
(9) $L$: maximum iterations.
(10) $J_m(U, V) = \sum_{i=1}^{n} \sum_{k=1}^{c} u_{i,k}^m d_{i,k}^2$ (1)

Objective function, it is the only standard to judge the sample point belong to which clustering center.

2.2.2. Procedure Of FCM Algorithm

(1) Set $\xi > 0$, maximum iteration $L$, initial clustering centers $V^{(0)} = \{v_1, \ldots, v_c\}$, set current iteration times $l = 1$.
(2) Membership matrix $U^{(l)}$ can be expressed as follows:

$$U_{i,k}^{(l)} = \left\{ \frac{d_{i,k}^{(l)}}{\sum_{i=1}^{n} \left( \frac{d_{i,k}^{(l)}}{d_{i,t}^{(l)}} \right)^{m-1}} \right\}, \forall i, k$$ (2)

When $d_{i,j}^{(l)} = 0$, set $u_{i,t}^{(l)} = 1$, $u_{i,k}^{(l)} = 0$, $k \neq t$.
(3) Get the new clustering centers $V^{(l+1)}$, the elements are as follows:

$$V_k^{(l+1)} = \frac{\sum_{i=1}^{n} (u_{i,k}^{(l)})^m \cdot x_i}{\sum_{i=1}^{n} (u_{i,k}^{(l)})^m}, \forall k$$ (3)

then set $l = l + 1$.
(4)When $\|v^{(l+1)} - v^{(l)}\| < \xi$ or $L \leq l$, stop, otherwise go to step (2).

3. FCM With Neighborhood Information

In the actual scene, the pavement images are often accompanied by noise. Standard FCM algorithm considers image as a collection of isolated pixels, while ignoring the spatial location of pixels. So the standard FCM algorithm is sensitive to noise. In this paper, neighborhood information was introduced to improve standard FCM algorithm. Common neighborhood system consists of 4-neighborhood system and 8-neighborhood system. In 4-neighborhood system, the center pixel is determined by four pixels (up, down, left, right) around it, while in 8-neighborhood system, the center pixel is determined by eight pixels (up, down, left, right, upper left, left down, upper right, right down) around it. Figure 1 shows 4-neighborhood system, and Figure 2 shows 8-neighborhood system. 8-neighborhood system was accepted in this paper. Literature[8] introduces median filter matrix, Literature[9] introduces mean filter matrix. But in actual situation, if the gray value of two pixels are very close, they are likely belong to same cluster, otherwise they are likely belong to different clusters.
In this paper, if the gray value of one pixel is very close to center pixel, this pixel will have a bigger impact on center pixel, otherwise the impact will be smaller. Unlike median filter and mean filter proposed in literature\[8\], literature[9], this paper adopts adaptive neighborhood information matrix, the detailed steps are as follows:

\[ p(c, j) = \sum_{i\in D} \left( |gray(j) - gray(i)| + \theta \right) \]

This is similarity function, \( P(c, j) \) shows the similarity between pixel \( j \) and center pixel \( c \), \( gray(j) \) is the gray value of pixel \( j \), \( D \) is 8-neighborhood area and the center pixel of this area is \( c \). \( \theta \) is a correction number. In 256-level gray image, we define \( \theta = 1 \). From the definition of similarity function, we can conclude that if the gray value of one pixel is closer to center pixel, the value of similarity function will be bigger, otherwise the similarity function will be smaller.

\[ f(c, j) = \frac{p(c, j)}{\sum_{j\in D} P(c, j)} \]

Influence function is defined based on similarity function. We can also conclude that if the gray value of one pixel is closer to center pixel, the value of influence function will be bigger, otherwise the influence function will be smaller.

(3). If \( f(c, j) \) reaches a certain value, pixel \( j \) and center \( i \) are likely belong to noise. In order to make this algorithm more robust to noise, a threshold value \( \xi \) is introduced in this paper. If \( f(c, j) \) is bigger than \( \xi \), set \( f(c, j) = 0 \), go to step (2), otherwise go to step (4).

(4). After the first three steps, a \( 3 \times 3 \) matrix can be achieved, the value of matrix center element is \( 0 \), the remaining elements are \( f(c, j), j \in D \).

\[
\begin{array}{ccc}
0.3020 & 0.2941 & 0.2980 \\
0.2902 & 0.2941 & 0.2902 \\
0.2941 & 0.2902 & 0.3098 \\
\end{array}
\]

\[
\sum_{i\in D} x_i f(c, i) = 0.2962
\]

Figure 3. Interior pixel

\[
\begin{array}{ccc}
0.0941 & 0.0941 & 0.0941 \\
0.0902 & 0.2941 & 0.0824 \\
0.0824 & 0.0902 & 0.0824 \\
\end{array}
\]

\[
\sum_{i\in D} x_i f(c, i) = 0.0889
\]

Figure 4. Noise pixel

\[
\begin{array}{ccc}
0.0784 & 0.0824 & 0.3020 \\
0.0745 & 0.2941 & 0.3020 \\
0.0745 & 0.0745 & 0.3098 \\
\end{array}
\]

\[
\sum_{i\in D} x_i f(c, i) = 0.2961
\]

Figure 5. Edge pixel

Through the above four steps, a neighborhood information matrix can be achieved, with this neighborhood information matrix, the center pixel can be replaced by eight pixels around it. With neighborhood information matrix, the \( d_{i,k} \) in membership function can be replaced with

\[
d_{i,k} = \left\| \sum_{i\in D} x_i f(c, i) - v_k \right\|_A
\]

. Usually noise pixels and edge pixels may lead to inaccurate
segmentation results. The presented algorithm in this paper performs more robust to noise than the standard FCM algorithm and can retain the boundary information effectively. Figure 3 to Figure 5 show the new gray value of interior pixel, noise pixel and edge pixel with adaptive neighborhood information matrix.

Figure 6. Synthetic image segmentation result

Figure 7. Real pavement image segmentation result
4. Results and Analysis

We use standard FCM algorithm, modified FCM algorithm in literature [9] and modified algorithm in this paper to do experiments on synthetic images and real pavement images respectively, analysis of experimental results are shown Figures 6 and 7.

4.1. Synthetic Image Segmentation Result

Synthetic image with $256 \times 256$ pixels was adopted in this experiment. Figure 6 lists two groups of segmentation results. The first group of images are original image, original image with $20\%$ salt&pepper noise, segmentation result with FCM algorithm, segmentation result with modified algorithm in literature[9], segmentation result with modified algorithm in this paper. The second group of images are original image, original image with mean 0, variance 0.01 Gaussian noise, segmentation result with FCM algorithm, segmentation result with modified algorithm in literature[9], segmentation result with modified algorithm in this paper.

4.2. Real Pavement Image Segmentation Result

There are four images in Figure 7, they are original image, segmentation result with FCM algorithm, segmentation result with modified algorithm in literature[9], segmentation result with modified algorithm in this paper.

From segmentation result shown in Figure 6 and Figure 7, we can conclude that compare with standard FCM algorithm and modified algorithm in literature[9], modified algorithm in this paper is more robust to noise and can retain the boundary information more effectively.

5. Conclusion

Standard FCM algorithm takes the pixel gray-scale information into account only, while ignoring the spatial location of pixels, so the standard FCM is sensitive to noise. Adaptive neighborhood information matrix was introduced in this paper, modify the membership function with neighborhood information matrix. The experiments by synthetic images and real pavement images show that the presented algorithm in this paper performs more robust to noise than the standard FCM algorithm and retain the boundary information effectively.

References