https://doi.org/10.17221/34/2019-JFS

A smoke image segmentation algorithm based on rough set and region growing

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Citation: Wang H.T., Chen Y.L. (2019): A smoke image segmentation algorithm based on rough set and region growing. J. For. Sci., 65: 321–329.

Abstract: Because the image fire smoke segmentation algorithm can not extract white, gray and black smoke at the same time, a smoke image segmentation algorithm is proposed by combining rough set and region growth method. The R component of the image is extracted in the RGB colour space, the roughness histogram is constructed according to the statistical histogram of the R component, and the appropriate valley value in the roughness histogram is selected as the segmentation threshold, the image is roughly segmented. Relative to the background image, the smoke belongs to the motion information, and the motion region is extracted by the interframe difference method to eliminate static interference. Smoke has a unique colour feature, a smoke colour model is created in the RGB colour space, the motion disturbances of similar colour are removed and the suspected smoke areas are obtained. The seed point is selected in the region, and the region is grown on the result of rough segmentation, the smoke region is extracted. The experimental results show that the algorithm can segment white, gray and black smoke at the same time, and the irregular information of smoke edges is relatively complete. Compared with the existing algorithms, the average segmentation accuracy, recall rate and *F*-value are increased by 19%, 21.5% and 20%, respectively.

Keywords: forest fire prevention; roughness histogram

Fires seriously threaten the safety of human life and property, and the occurrence of fires is detected in a timely and accurate manner, it can provide valuable time for fire fighting and evacuation, and it reduces various hazards which are caused by fire. In the early stage of the fire, the smoke appeared earlier than the open flame, it was not easily blocked by the obstacles, and the early warning of the fire was realized. Video smoke detection is to determine whether a fire has occurred by analyzing the image characteristics of smoke, the segmentation of suspected smoke areas is the premise of feature extraction and recognition. At present, the motion characteristics, colour characteristics and energy analysis of smoke are mainly used to segment the suspected smoke region. There are commonly the frame difference method (Yu et al. 2013), three-frame difference method (Shi et al. 2015) the improved Kalman filter (Zhang et al. 2016) and Gaussian mixture model (GMM) (Wu et al. 2008; Zen et al. 2013), these methods are used to detect the motion region in the smoke image. The motion region of the current frame is calculated by using a motion history image (MHI) (Ho 2009). Combining the motion and colour characteristics of smoke is also a common method of smoke image segmentation. A significant smoke detection model was established by the colour and dynamic characteristics of smoke (Jia et al. 2016; Bchir et al. 2019). A smoke segmentation method was proposed based on saliency detection. The calculated motion energy function was constructed from the calculated motion foreground, and the saliency spectrum

Supported by National Natural Science Foundation, Project No. 51304076 of China (it is supported by Natural Science Foundation Project No. 14JJ4064 of Hunan Province)

https://doi.org/10.17221/34/2019-JFS

was estimated to obtain the suspected smoke area. In the Lab colour mode, the smoke static feature is identified (Lin et al. 2013), and the motion region is extracted by the background difference method, the background is updated by the adaptive background which was generated by the adaptive threshold. The motion and energy characteristics of smoke were used (Zhao et al. 2015), the energy of the image is obtained by the movement of the smoke halo and the wavelet transform, and with reference to the colour characteristics of the smoke, the CS Adaboost algorithm is used to identify the smoke area.

When a fire occurs, the colour of the smoke is affected by the burning material, it is mainly white, grayish white and black. The above method can solve the problem of segmentation of white, grayish-white or black smoke, but it is impossible to simultaneously separate the smoke of different colours. It is obviously not comprehensive to study the segmentation of one of the colour smoke images. To this end, in this paper, a smoke segmentation algorithm is proposed by combining rough set and region growth to achieve the purpose of simultaneously splitting white, off-white and black smoke. The image is regarded as a knowledge system. The concept of upper and lower approximation is used in rough set theory, the rough segmentation of the smoke image is completed according to the roughness histogram of the image. At the same time, the motion difference region is detected by the frame difference method, and then the colour model of the smoke is established in the RGB colour space. The interference object is removed in the motion region, and the appropriate seed point is selected in the smoke region. The region is grown on the result of the rough set segmentation, the final smoke segmentation result is obtained.

MATERIAL AND METHODS

Smoke image segmentation based on rough set

Rough sets theory is a data analysis theory to quantify inaccurate, inconsistent and incomplete information and knowledge, it was proposed by the Polish mathematician Pawlak in 1982 (Lizarraga-Morales et al. 2014). In this theory, the non-empty finite set of objects is called the universe, denoted U. Any subset X ($X \subseteq U$) in the domain U is called a concept or category in U. Any conceptual cluster in the domain U is called knowledge. Rough sets describe knowledge from the perspective of pattern classification, knowledge is seen as the ability to classify objects without the need for any additional prior information, and the collection of useful information can be accomplished by simply gathering itself information.

Rough set basic concept

Definition 1: Let the equivalence class of the equivalence relation R form a division on the domain U as $\{X_1, X_2, \cdots, X_n\}$, it is denoted as U/R, and the contained equivalence class is recorded as $[x]_R$. R={R} is an equivalence relation cluster on the domain U, it constitutes the information system, such as the knowledge base $K = (U, R)$. If $P \subseteq R$ and $P \neq \varnothing$, then the intersection of all equivalence relations in P is also an equivalence relation, it is called the indistinguishable relationship on P, it is denoted as ind (P), and there is the equation (1):

$$\forall x \in U, [x]_{ind(P)} = [x]_P = \bigcap_{R \in P} [x]_R \tag{1}$$

Definition 2: The lower approximation set represents a set of objects that are definitely X, and $X \subseteq U$ is a subset on U, then the under approximate set of X's R is the equation (2):

$$\underline{R}(X) = \bigcup \{[x]_R \in U/R \mid [x]_R \subseteq X\} \tag{2}$$

The upper approximation set represents a collection of objects that may belong to X, then the upper approximate set of X's R is the equation (3):

$$\overline{R}(X) = \bigcup \{[x]_R \in U/R \mid [x]_R \bigcap X \neq \phi\} \tag{3}$$

Definition 3: The accuracy reflects the completeness of the knowledge cognition which is represented by the set X. The precision is defined as the equation (4):

$$d_R(X) = \frac{|\underline{R}(X)|}{|\overline{R}(X)|} \tag{4}$$

Roughness is used to measure the inaccuracy degree of the set X, it reflects the degree of incompleteness of the knowledge which is expressed by the set X, roughness is defined as the equation (5):

$$\rho_R(X) = 1 - d_R(X) = 1 - \frac{|\underline{R}(X)|}{|\overline{R}(X)|} \tag{5}$$

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As can be seen from the basic concept of the above rough set, the degree of uncertainty of the set can be calculated by the knowledge itself without any additional prior information. In image segmentation, the whole image can be regarded as a knowledge base. The idea of rough set inseparable relationship, upper and lower approximation is used to make image segmentation simple and more robust.

Roughness measure of colour images

The histogram of the image is used as the lower approximation, and the Histon histogram is used as the upper approximation, and the roughness is calculated to obtain the roughness histogram (Cai et al. 2011). Let I be an RGB image with a size of $M \times N$, then the statistical histogram of I on the three primary colour components of R, G, and B, ie, the lower approximation, can be expressed as equation (6):

$$\underline{H}_i(g) = \sum_{m=1}^{M}\sum_{n=1}^{N}\delta(I(m,n,i) - g) \quad (6)$$

Where $0 \leq g \leq L-1$ and $i \in$ {R, G, B}; δ (·) represents a pulse function; I (m, n, i) represents the grayscale value of the pixel I (m, n) on the i component; L is the maximum gray level.

$P \times Q$ is the neighborhood of the pixel I (m, n), and the sum of the distances between I (m, n) and all the pixels in the neighborhood is the equation (7):

$$d_{P\times Q}(m,n) = \sum_{p\in P}\sum_{q\in Q} d(I(m,n), I(p,q)) \quad (7)$$

Where d (I (n, n), I (p, q)) represents the Euclidean distance between pixel I (m, n) and pixel I (p, q):

$$d(I(m,n), I(p,q)) = \sqrt{\sum_{i=R,G,B}(I(m,n,i) - I(p,q,i))^2} \quad (8)$$

A threshold is set, if the sum of the distances of the pixel and other pixels in the colour feature space in the neighborhood is less than the threshold, the pixels in the neighborhood are considered to be homogenous in colour. Homogeneity calculation is equation (9):

$$H(m,n) = \begin{cases} 1, d_{P\times Q}(m,n) < T \\ 0, else \end{cases} \quad (9)$$

Where T is the given threshold. At this point, the Histon histogram is similarly defined as equation (10):

$$\overline{H}_i(g) = \sum_{m=1}^{M}\sum_{n=1}^{N}(1 + H(m,n))\delta(I(m,n,i) - g) \quad (10)$$

Where $0 \leq g \leq L-1$ and i ∈ {R, G, B}.

According to the related concept of the rough set, combined with the basic histogram and the Histon histogram, the roughness of the corresponding gray level can be obtained, and the roughness histogram is obtained, and the roughness is the equation (11):

$$\rho_i(g) = \frac{|\underline{H}_i(g)|}{|\overline{H}_i(g)|} \quad (11)$$

Where $0 \leq g \leq L-1$ and i ∈ {R, G, B}. In the threshold segmentation algorithm, the peaks of the histogram represent different regions, and the valleys represent the boundaries between different regions. Similar to this idea, the roughness measure can be applied to the segmentation of the image, the pixel at the peak of the roughness histogram may be located in a region where the colour change is relatively small, that is the center of each region in the image, the pixels of the map valley in the roughness histogram may be located in a region where the colour changes relatively large, that is the boundary between the regions. Therefore, by selecting effective peaks, the bands are divided for the gray components of the respective colour components, an appropriate segmentation threshold is found, the image segmentation can be completed. The top and bottom approximations of white smoke and black smoke and roughness histogram are shown in Fig. 1(b) and Fig. 2(b).

Smoke image rough segmentation

For smoke images, due to the lack of colour tone of the smoke, whether it is white, off-white, or black smoke, the value of the R, G, and B components is not much different, ie, R≈G≈B. Therefore, in this paper, the single R component of the colour smoke image is used to measure the homogeneity between the neighborhood pixels, then the roughness histogram is constructed based on the R component, so that the calculation amount is greatly reduced.

According to the nature of the roughness function, it is necessary to find the position of the effective peak and the trough in the histogram of the roughness, and the band is divided for the gray of the red component. The threshold of the segmented image is found, the segmentation of the smoke image is completed.

In this paper, the distribution information of the peaks is used to adaptively select the segmentation threshold. The specific steps are as follows (Xie 2011):

Step 1: Calculate all peaks P_k: P_{g_1}, P_{g_2}, ···, P_{gk} from the roughness statistical histogram, g_i represent

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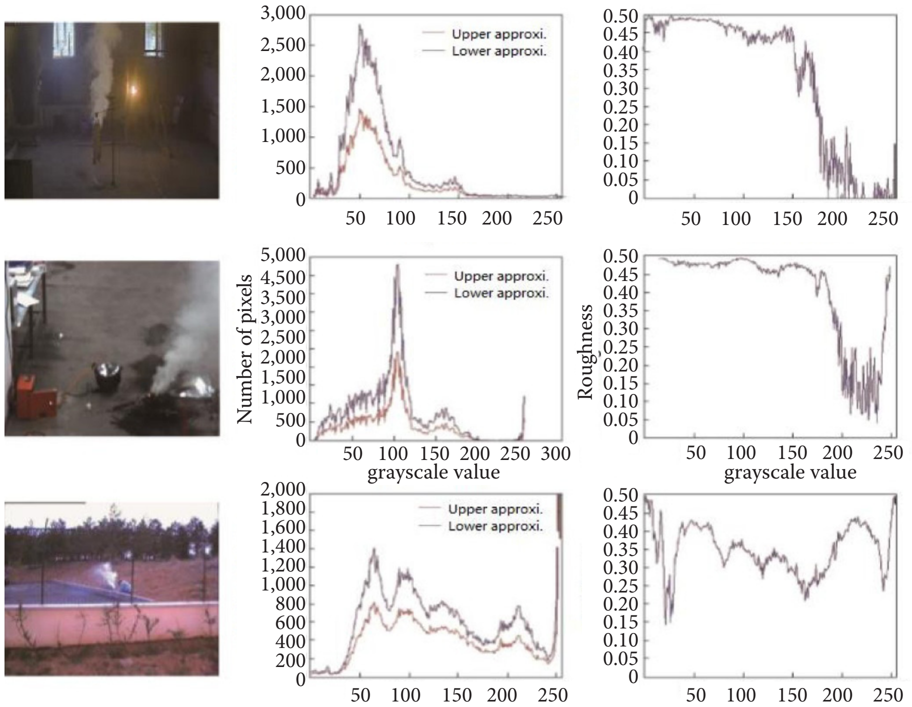
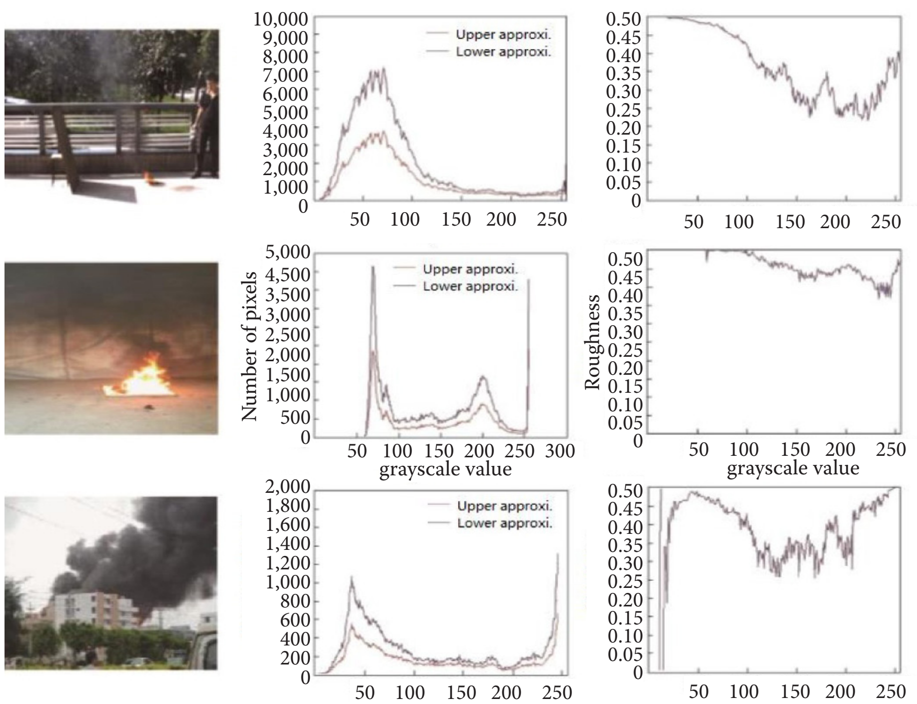


(a) smoke image (b) upper, lower approx. histogram (c) roughness histogram

Fig. 1. Rough representation of white smoke image



(a) smoke image (b) upper, lower approx. histogram (c) roughness histogram

Fig. 2. Rough representation of black smoke image

the gray value of the pixel to which the peak P_{gi} belongs, and $g_1 < g_2 < \cdots < g_k$.

Step 2: Find the maximum value P_{max} and the minimum value P_{min} in P_k, and calculate the mean $\mu = (P_{max} + P_{min})/2$, then calculate the standard deviatio n of the peak and the mean $\sigma = \sqrt{\sum (P_{gi} - \mu)^2/k}$.

Step 3: Set the height threshold $T_h = \mu - \sigma$, and eliminate some unimportant peaks according to this threshold to form a new peak sequence.

Step 4: Set the width threshold T_w, and obtain a suitable width threshold range by statistical analysis of a large number of smoke-containing images,

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Fig. 3. Smoke image coarse segmentation results based on rough set

the range of T_w is 50–70. When the width of the gray value adjacent to the two adjacent peaks is less than the set threshold, the larger one is retained and the other is eliminated, so that the final effective peak is selected.

Step 5: Select the trough and take the minimum between each two peaks to get the trough.

Step 6: According to the selected trough, the gray level on the red component of the smoke image is divided into different bands, and the gray weight value in each band is used as the gray average value of the pixels in the band, thereby coarse segmentation is completed for the image of the smoke.

The rough image R component smoke image is roughly segmented for each image in Fig. 1(a) and Fig. 2 (a), the results are shown in Fig. 3.

Smoke image segmentation based on regional growth

After the R component of the image is roughly divided into rough sets, several R component colour classes can be obtained, and each colour class has the same gray value. The basic idea of the regional growth method is to use seed pixels as a starting point for growth (Wu et al. 2008), pixels are combined with similar properties to form a region. Therefore, the region growth can be performed on the rough segmentation of the rough set, thereby the foreground image is extracted for the smoke image.

Select the seed point for growing in the area

According to the characteristics of the smoke area to be segmented, a method of automatically selecting seed points is proposed based on the motion characteristics and colour characteristics of smoke.

(1) Original image motion area detection

When a fire occurs, the smog is obviously affected by the heat. In the detection of the motion region, the motion target is extracted by analyzing the changed region in the image. The interframe difference method is not only simple in calculation, but also there is good in real-time, and it is less affected by environmental changes. Therefore, this method is used to extract the motion region, there is the equation (12):

$$D_i(x,y)=\begin{cases}1,|F_i(x,y)-F_{i-1}(x,y)|>1\\0,else\end{cases} \quad (12)$$

Where T is the set threshold, it is determined by OSTU (Maximum Inter-Class Variance Method) (OTSU 1979); $F_i\,(x, y)$ represents the current frame image; $D_i\,(x, y)$ represents the motion extraction result, and the foreground image of the motion is marked as 1, The background is marked as 0.

(2) Establish a smoke colour model

Due to the difference in combustion materials and combustion conditions, the colour of the smoke is mainly white, grayish white and black. By analyzing the video images of different colour smoke which is generated by different combustion materials in different environments, a colour model is established in the RGB colour space, it is suitable for different colour smokes, and the true colour images of the adjacent two frames of images are further processed. The smoke colour model is the equation (13) (Zhao 2015):

$$\begin{cases}C_{max}=\max(R,G,B)\\C_{min}=\min(R,G,B)\\V=\dfrac{R+G+B}{3}\\rule\;1:|C_{max}-C_{min}|<T_1\\rule\;1:T_2<V<T_3\end{cases} \quad (13)$$

In the equation, rule 1 and rule 2 represent the colour rule of smoke. According to the colour characteristics of smoke, T_1 in rule1 generally takes 15~30; T_2 and T_3 in rule 2 are the brightness range

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of smoke, and the range of gray (white) smoke is 80~220, the black smoke brightness range is 20~80, so T_2 takes 20~80, T_3 takes 80~220; if the pixel of the motion area satisfies rule 1 and rule 2, the pixel is marked as 1, otherwise it is marked as 0.

(3) Determine the seed point

After (1) and (2) treatment, a suspected smog area is obtained, and morphological corrosion treatment is performed to narrow the selection range of the seed point. In the binary image after corrosion, white is the smoke area, and a random point is selected in the white area as the seed point for the region growth. In this article, the first pixel is used in the white area as the seed point for region growth.

Regional growth

According to the coarse segmentation results of the smoke image, the growth criteria are formulated:

Step 1: In the result of coarse segmentation of the rough set, the seed points of the region growth are selected, and the pixel points are compared with the same or similar colour features in the surrounding four neighborhoods. If the gray scale difference is less than a predetermined threshold, these pixel points are merged to the area where the seed point is located.

Step 2: Focusing on the newly merged pixel, returning to the previous step, checking the neighborhood of the new pixel until the region cannot be further expanded. When all the pixels have belonged, the entire growth process is ended, and the region is marked as 1 where the seed point grows out, other areas are marked as 0.

Step 3: The binary segmentation result of the region growth is subjected to morphological processing, and the open operation is used to remove scatter and burrs.

RESULTS

MATLAB (Version 7.10, 2010) development environment is used in this paper, the simulation experiments of smoke video were carried out in 6 different environments to verify the effectiveness of the proposed algorithm. At present, there is no standard video database for fire video recognition. The video in this article is from the Internet and the video captured by the research team. The video environment is described in Table 1.

Table 1. Video environment description

Video	Video description	Colour
Video 1	indoor cotton rope smoldering, simple background, bright white windows, light interference	grayish white
Video 2	indoor wood smoldering, complex background, steam interference	white
Video 3	outdoor wildfire, complex background, wind, sky, pedestrian interference	white
Video 4	outdoor small fire, complex background, swaying leaves, pedestrian interference	black grey
Video 5	indoor fire, simple background, flame brightness, shaking interference	black
Video 6	resident building fire, complex environment, thick smoke	black

The purpose of smoke segmentation is to obtain a relatively complete area of suspected smoke. In this paper, the literature (Jia et al. 2016) and the literature (Lin et al. 2013), the motion characteristics and colour features of smoke are combined to separate the smoke image. Therefore, the paper compares the results with the literature (Jia et al. 2016) and (Lin et al. 2013). The results are shown in the Fig. 4. In the literature (Jia et al. 2016), the colour and motion characteristics of smoke is used to nonlinearly enhance the image, so that the image has better significance, but this method also enhances the non-smoky motion region similar to the smoke colour. Due to the fire environment and the uncertainty of the combustion materials, when the environment is complex or the smoke concentration is low, the complete and different colour smoke areas cannot be obtained. The segmentation result is shown in Fig. 4(b). The detection model of smoke image is established in Lab colour space (Lin et al. 2013), and the suspected smoke area is segmented. Then the adaptive background is constructed by adaptive threshold, and the motion region is extracted by background difference method. However, due to the complexity of the monitoring environment, the uncertainty of the combustion materials and the large amount of calculation, the speed of background update cannot be adaptive to the speed of smoke generation. The segmented smoke area has large voids, it is also difficult to obtain a complete smoke area of different colours, and the segmentation result is shown

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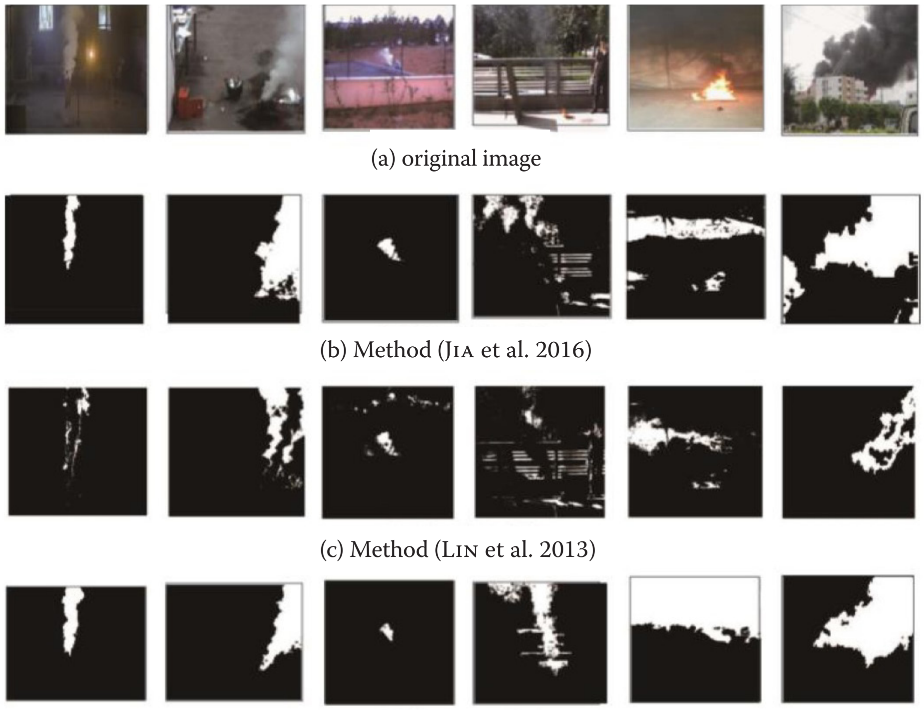

(a) original image

(b) Method (Jia et al. 2016)

(c) Method (Lin et al. 2013)

(d) The proposed method

Fig. 4. Comparison of segmentation results by different methods

in Fig. 4(c). Combining the motion characteristics and colour characteristics of smoke, the frame difference method and the smoke RGB colour model are applied in smoke segmentation, and one point is used in the segmented smoke region as a seed point, the seed point region is smaller, the probability of the selected seed point being a smoke pixel is higher. Therefore, the smoke region is obtained by combining the smoke motion feature and the colour feature segmentation, it can be used as the seed point region. Finally, the region is grown on the rough segmentation result, and the segmentation result is shown in Fig. 4(d).

DISCUSSION

It can be seen from the segmentation results that the proposed algorithm can segment relatively complete smoke regions, and the boundary irregular information retention is also complete. It solves the problem that the complete white, grayish white, black smoke problem cannot be simultaneously separated relatively in the literature (Jia et al. 2016) and (Lin et al. 2013).

The average values of precision, recall, and *F*-values were compared with those of the literature Jia et al. 2016 and Lin et al. 2013. In the smoke image segmentation, the manually segmented binarized smoke region is taken as the real data set, it is denoted as A, the smoke region is segmented by the algorithm, and the pixel set it belonging to A, it is denoted as B, if the pixel set is not belonging to A, it is denoted as C. Assuming that the number of pixels in sets A, B, and C are a, b, and c, respectively, the precision, recall, and *F*-values are equations (14), (15), and (16), respectively:

$$precision = \frac{b}{b+c} \tag{14}$$

$$recall = \frac{b}{a} \tag{15}$$

$$F = \frac{(1+\beta^2) \times precision \times recall}{\beta^2 \times precision + recall} \tag{16}$$

The *F*-value is a comprehensive evaluation index of combining the recall rate and the accuracy rate, taking $\beta^2 = 0.3$ (Ren et al. 2014). Fig. 5 depicts a quantitative comparison of the accuracy, recall, and *F*-values of the six-segment video by using the algorithm and the literature (Jia et al. 2016) and (Lin et al. 2013). It can be seen from Fig. 5 and Table 2 that the accuracy, recall and *F*-value of the

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Table 2. Comparison of different methods for mean precision, recall and F-value

	Proposed method	Method	
		(Jia et al. 2016)	(Lin et al. 2013)
Mean precision	0.95	0.83	0.69
Mean recall	0.81	0.68	0.51
Mean F-value	0.92	0.81	0.63

smoke image segmentation algorithm are higher than those in the literature (Jia 2016) and literature (Lin et al. 2013), it proves the effectiveness and advancement of the proposed algorithm.

In terms of segmentation accuracy, recall rate and F-value, why the proposed algorithm is superior to the literature (JiaY et al. 2016) and (Lin et al. 2013), the main reason is that the rough centralized knowledge is used to classify objects. The „reunion" white, grayish white, black smoke can be divided into one class more completely. The accurate frame difference method is used in smoke segmentation, and the RGB colour model of smoke is established. The smoke region can be segmented more accurately, and then the region growth algorithm is used. The appropriate seed points are selected in the region, and the region is grown on the result of the rough set segmentation to obtain the final smoke segmentation result. Rough set rough segmentation guarantees the integrity of the smoke segmentation result. The method of seed point selection in the region growing method ensures the accuracy of the segmentation result. Therefore, combining the rough set with the area growing method results in an increase in the accuracy, recall, and F-value of the smoke segmentation.

CONCLUSION

In this paper, a smoke image segmentation algorithm is proposed by combining rough set and region growing method. The rough set segmentation method can divide the image into several colour classes, then the frame difference method and the colour model are used to segment the smoke region. In this region, the seed points are selected, and the region growth is performed on the result map of the rough set segmentation. The result of the segmentation of the complete smoke area can be obtained. In this paper, the smoke segmentation algorithm can segment relatively complete white, gray and black smoke at the same time, and the accuracy and recall rate of the algorithm and the F-value are also improved. The experimental results show that the proposed algorithm can effectively solve the segmentation problem of different colour smoke, and the segmented smoke area is more complete and accurate.

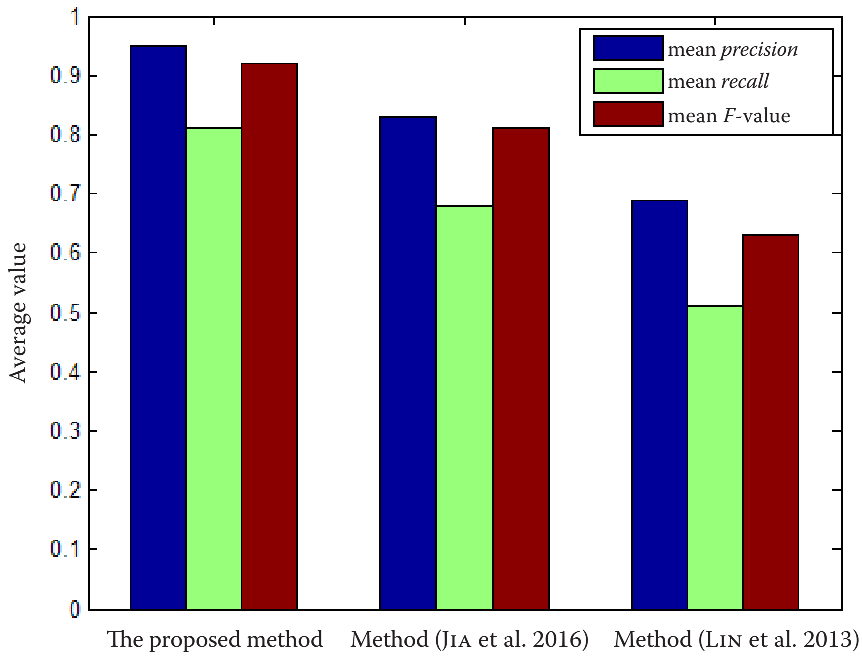

Fig. 5. Comparison for mean precision, recall and F-value

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Received for publication March 24, 2019
Accepted after corrections August 16, 2019