Auto-recognition of typhoon cloud based on boundary features

LU Juan[1], ZHANG Changjiang[1,2,3], ZHANG Xiang[1], YANG Bo[1], DUANMU Chunjiang[1]

1. *College of Mathematics, Physics and Information Engineering, Zhejiang Normal University, Zhejiang Jinhua* 321004, *China*;
2. *State Key Laboratory of Remote Sensing Science, Jointly Sponsored by the Institute of Remote Sensing Applications of Chinese Academy of Sciences and Beijing Normal University, Beijing* 100101, *China*;
3. *State Key Laboratory of Severe Weather/Chinese Academy of Meteorological Sciences, Beijing* 100081, *China*

Abstract: Typhoon has different characteristics, such as texture, shape, and area, in different development stages. We could not automatically recognize the typhoon clouds in all stages based on these features. During different development stages, typhoon all has helicity and non-typhoon has no helicity. Based on this, we extract boundary information of clouds and statistics of the rotation degree of boundary clouds in single satellite image. In this paper, we use curvature curve of Bezier histogram to obtain two segmentation thresholds, iteratively segment the satellite image, and combine typhoon's geometric features, such as rotation, area and shape to recognize the typhoon. Experimental results show that the typhoon can be recognized effectively in all different development stages.

Key words: typhoon recognition, geometric features, Bezier histogram, curvature, circle-like, rotation

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1 INTRODUCTION

The correct recognition of typhoon cloud system is the prerequisite for accurate prediction of typhoon, and it has a certain degree of difficulty in satellite images. Up to now, Chinese and international scholars have done many researches in the cloud system identification. The research work focused on the use of clouds' gray, texture and statistical features, by means of neural networks, fuzzy techniques, mathematical morphology and fractal geometry and other mathematical tools to identify the typhoon cloud system (Vannoorenberghe & Flouzat, 2006.; Ooi & Lim, 2006; Lopez *et al.*, 2004; Intajag *et al.*, 2006). Yu *et al.* (1996) segmented cloud regions with mathematical morphology, then calculated texture features of typhoon cloud probability density, and used BP neural network combined with fuzzy identification technology to identify typhoon cloud system in the GSM cloud image. Liu *et al.* (2001a) obtained the segmentation thresholds with Otsu method, iteratively segmented, then combined the area feature of typhoon clouds to identify typhoon clouds. Liu *et al*. (2001b) used the fractal dimension and GGCM to extract the texture features of objectives, such as typhoon dense clouds in satellite images, and recognized clouds. Wang *et al.* (2008) combined with the main cloud of typhoon with higher gray value, larger area and limited scope of activities, made use of threshold method, mathematical morphology and mathematical statistics method, and studied the typhoon cloud segmentation of Lambert image. Hao *et al.* (2002) identified typhoon cloud by introducing vectorial moment to characterize the overall distribution of the image texture. The above methods are all based on particular characteristics of typhoon clouds, such as texture and shape, which can change in different stages of the typhoon cloud. We cannot auto-recognize the typhoon clouds in all stages based on these features.

During different development stages, typhoon all has helicity, so that we extract boundary information of clouds and statistic the rotation degree of boundary clouds in single satellite image. In this paper, we use curvature curve of Bezier histogram to obtain two segmentation thresholds, iteratively segment the satellite image, and combine typhoon's geometric features, such as rotation, area and shape to recognize the typhoon. Experimental results show that the typhoon cloud can be effectively recognized by the proposed method in all different development stages.

2 ALGORITHM DESCRIPTION

2.1 Algorithm theory

Typhoon is a tropical cyclonic disturbances evolved low-pressure system. In the northern hemisphere, the airflow around the typhoon center has counterclockwise rotation, and vice versa in the southern hemisphere. In the process of the

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First author biography: LU Juan (1985—), female, Master of Zhejiang Normal University, engages in image processing. E-mail: lujuan104@163.com

Corresponding author: ZHANG Changjiang, E-mail: zcj74922@zjnu.cn

generation, development, mature and dying stages, typhoon cloud has different texture, shape and other characteristics. It is difficult to identify the cloud with a single particular pattern. Compared with the other cloud systems, typhoon cloud has its special characteristics: In general, the diameter of main cloud of typhoon reaches at least up to 150km, and there is a better circle-like. The cloud of typhoon is an "organized" system at any stages of development. As the center of typhoon has great absorbability, the surrounding area of the clouds are rotated around the center, even in the dying stages, typhoon broken, it still has the vortex structure. Based on the above characteristics, we can remove part of cloud bands, which has no circle-like, and the smaller cloud system. Then the rotation feature can be used to distinguish the typhoon cloud between vast majority non-typhoon clouds. Cloud Motion Wind is used to describe the rotation characteristics of clouds, which also has shortcomings: On one hand, Cloud Motion Wind's expression needs many continuous satellite cloud images, it can not be depicted just in a single satellite image. On the other hand, it is difficult to know if the cloud is rotary automatically, even if we has the Cloud Motion Wind. In this paper, we extract information from edge cloud in a single satellite image, based on its ablity to reflect rotation characteristic more or less, and statistics the degree of rotation of clouds, then combine other features, such as circle-like, to recognize typhoon cloud.

2.2 Select segmentation threshold of satellite images

Segmentation threshold affects the segmentation result and the integrity degree of the main typhoon cloud. The background of satellite image is complex, and gray distribution of targets is uneven. How to select an adaptive threshold value is very difficult in identifying the main body of the typhoon cloud. There are many threshold selection methods now, such as iterative method, maximum entropy threshold method, clustering algorithms, and so on. They can achieve a good threshold sometimes, and a good result can be obtained by these methods only part of the satellite images in identifying typhoon cloud. In the original satellite image, gray values of the same structure cloud are quite close, pixels of typhoon cloud are more concentrated and gray values of typhoon cloud are higher. Corresponding to histogram, gray values of similar parts are very similar, and most of them form specific peaks. Considering these characteristics, we select the gray threshold by using the curvature of Bezier histogram curve (Jin *et al.*, 2004). The two parameter equations of position coordinates of Bezier curves are as follows:

$$x(t) = \sum_{k=0}^{L-1} x_k B_{k,L-1}(t) \tag{1}$$

$$y(t) = \sum_{k=0}^{L-1} y_k B_{k,L-1}(t) \tag{2}$$

The gray level of original image is quantified into L. (x_k, y_k), k=0,1,2,⋯,L−1 are the location of all control points of gray histogram. $0 \leqslant t \leqslant 1$, $B_{k,L-1}(t)$ is harmonic function of various points position vector along Bezier curve, Its expression is:

$$B_{k,L-1}(t) = \frac{(L-1)!}{k!(L-k-1)!} t^k (1-t)^{L-k-1} \tag{3}$$

The curvatures of control points in Bezier histogram can be solved if use the following formula:

$$\mathrm{Cur}(t) = \frac{x'(t)y''(t) - y'(t)x''(t)}{(x'(t)^2 + y'(t)^2)^{3/2}} \tag{4}$$

$x'(t)$ and $y'(t)$ are first derivative, $x''(t)$ and $y''(t)$ are second derivative, they can be calculated as follows:

$$\begin{cases} x'(t) = 1/2[x(t+1) - x(t-1)] \\ y'(t) = 1/2[y(t+1) - y(t-1)] \end{cases} \tag{5}$$

$$\begin{cases} x''(t) = x(t+1) - 2x(t) + x(t-1) \\ y''(t) = y(t+1) - 2y(t) + y(t-1) \end{cases} \tag{6}$$

Peak points of curvature correspond to valley points of the histogram curve. According to the actual characteristics of typhoon cloud, this paper takes some peak points of curvature of Bezier histogram curve as gray threshold. Experiments prove that taking one of these peak points as the threshold can separate part of clouds, but have poor adaptability, on account of different images have different peak points. In addition, the contrast of original satellite image also has greater impact to segmentation results. To improve the segmentation result, we enhance the original satellite image firstly, and linear stretched the enhanced satellite image. The process can enhance satellite cloud contrast and improve adaptive threshold.

2.3 Criterions of recognizing typhoon cloud system

In general, typhoon cloud has a larger area, bright gray value, and good circle-like. We can use circle-like and area as a criteria to identify typhoon cloud. Circle-like is defined as (Yu, 2008):

$$Y = \frac{4\pi A}{C^2} \tag{7}$$

where A indicates the area of cloud and C is the cloud's circumference.

As cloud is a highly irregular geometry, edges details may be too much, make circumference very large, then Y is small even if the cloud has good circle-like. The result is far from ideal. To recognize typhoon cloud, Eq. (7) is improved as:

$$K = Y \times A^{1.8} \tag{8}$$

where K is a criteria to identify typhoon cloud, and anther criteria is the rotation degree of clouds. The rotation information embodies in the edge of single cloud image, as shown in Fig.1:

Fig. 1 (a) is cropped fused image of typhoon Sepat, No. 9 Typhoon, at 8 o'clock on August 16, 2007. We can get rich information of helix from the image. Just a single satellite cloud image, we can see the edge turn around the center of typhoon cloud system, majority of angles that between edge clouds and the main cloud are acute angle, when along counter-clockwise, and non-typhoon clouds are not. Considering typhoon cloud of various periods, combined with the typhoon cloud all has vor-

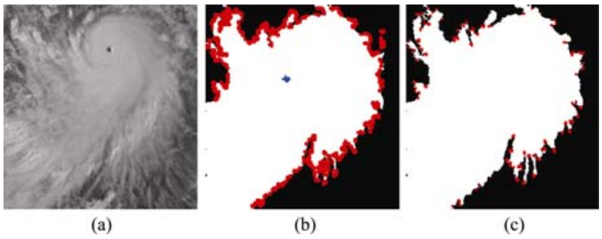

Fig. 1 Rotation information in single satellite image
(a) Cropped typhoon; (b) Corners and centroid of the cloud; (c) Concave and convex foints of the cloud

ticity, we can recognize most typhoon cloud by get degree rotation of all clouds. We statistic the angle between edge clouds and the main cloud along counter-clockwise to get degree rotation. The specific calculation methods are as follows:

(1) Binary satellite image, remove broken scattered clouds, and fill empty space which in enclosed area of clouds, avoid detecting corner points which are inside of clouds.

(2) Detect corner points with Harris algorithm on the edge of clouds, that is, calculate 2×2 autocorrelation matrix at each pixel:

$$G = w|(\nabla I)(\nabla I)^{\mathrm{T}}| \tag{9}$$

$$H = \det(G) - h(\mathrm{trace}(G))^2 \tag{10}$$

where w is gaussian smoothing template, and h is a constant (it is set as 0.04). We define the point as corner point when H is big enough.

(3) Find convex - concave points of edge clouds, as follows: Calculate centroid a of cloud, order corner points which get from above step counter-clockwise, obtain counter-clockwise sequence of corners J_i, $i=1,2,\cdots,n$, where n is the number of corner points. Calculate the distance d_i from each corner point to centroid a. Then calculate difference Δd_i between adjacent distances.

$$\Delta d_i = \begin{cases} d_i - d_{i-1}, 2 \leqslant i \leqslant n \\ d_i - d_n, \quad i = 1 \end{cases} \tag{11}$$

Detect the jump points of Δd_i, $i=1,2,\cdots,n$, if Δd_i changed from positive to negative, i will be saved as a concave point; if from negative to positive, i is saved as a convex point.

The red points are edge corner points which detect with Harris algorithm and the blue point is the centroid a in Fig.1 (b). And Fig.1 (c)'s red points are convex – concave points which we get as above.

(4) Compute angles between convex points and the main cloud: Paint directed line segment $\overrightarrow{AB}$ whose endpoints are two adjacent concave points A, B (A, B according to counter-clockwise order). Obtain the midpoint C of $\overrightarrow{AB}$, connect the convex points D that between concave points A and B to C, obtain a line DC, calculate angle θ_i between DC and $\overrightarrow{AB}$.

(5) Statistic the proportion of acute angle in all θ, recorded as rotation degree Z. If the proportion is over 80%, the cloud system can be judged as having the characteristics of rotation. In the northern hemisphere, we calculate rotation degree with an acute angle to Identify typhoon, and with obtuse angle to calculate rotation degree in the southern hemisphere. (Satellite images has latitude information, therefore, it is able to identify the northern and southern hemispheres automatically according to cloud that is.)

In theory, all angles are acute angles or obtuse angles can judge cloud has rotation feature. In this paper, due to binary satellite image causes to miss some edge information, and there are also some errors in detecting concave-convex points. We choose 80% as determine boundaries.

Combined area of typhoon cloud, circle-like and rotation feature, Eq. (13) is used to identify cloud. The cloud which has the largest TP is identified as the main typhoon cloud.

$$R = \begin{cases} Z, Z > 80\% \\ 0, Z \leqslant 80\% \end{cases} \tag{12}$$

$$\mathrm{TP} = KR \tag{13}$$

2.4 Algorithm

The algorithm flow chart is shown in Fig. 2:

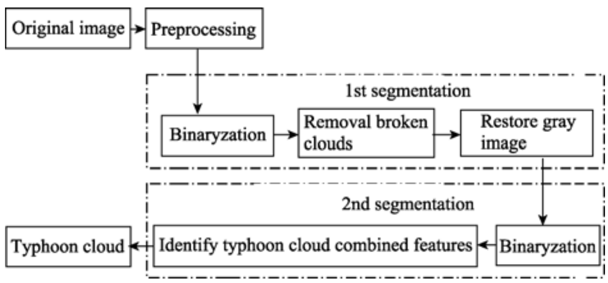

Fig. 2 Flow chart of proposed method

2.4.1 Preprocessing

Preprocessing consists of three parts:

(1) Intercept typhoon region from original image. FY-2C satellite image shows clouds on a global scale. The calculation burden is very large if we directly deal with whole image. Typhoon activity area is relatively small, and we intercept part of northwest pacific which is the activity area of typhoon from the original image (size 800×800) to recognize typhoon cloud.

(2) Fuse multi-channel intercepted images. We have done lots of work to get complete information of Typhoon cloud from multi-channel satellite images. In this paper, we fuse 5-channel satellite images with NSCT combining the principle of energy (Lu *et al.*, 2009), and save the fused image for subsequent processing.

(3) Enhance image. Enhance the fused image in order to obtain self-adaptive threshold (Chen, 2006). As wavelet of symmlet series has approximately symmetry, we enhance high-frequency detail in all directions with sym4 (2-layer). Then linear stretch is implemented to the enhanced image.

2.4.2 Cloud segmentation

Segmentation one time can not separate all cloud, and we segment cloud two times. The first threshold is obtained by following equation:

$$T_1 = \frac{P_1(\mathrm{int}(0.6N)) + P_1(\mathrm{int}(0.7N))}{2} \tag{14}$$

where N is the number of peaks of curvature of Bezier histogram curve, int stands for rounding, $P_1(N)$ is the gray value that the Nth peaks corresponding.

We choose a coarse threshold in the first segmentation, and then combined the feature of area to delete part of background and clouds which have small area, restore to gray image, preparing for the second segmentation. Recalculate curvature of Bezier histogram curve after the first segmentation. The second segmentation threshold need to distinct clouds from background, disconnect connection between clouds, and retain the integrity of clouds. Finally, the second threshold can be obtained as follows:

$$T_2 = \frac{2P_2(\mathrm{int}(0.6N)) + P_2(\mathrm{int}(0.7N))}{3} \tag{15}$$

where $P_2(N)$ is the gray value that the Nth peaks corresponding to curvature of Bezier histogram curve after having finished the first segmentation to the satellite cloud image.

After the second segmentation, we obtain independent clouds, and then use different pseudo-color tag clouds, calculate area, perimeter, roundness and rotation degree of each cloud, get TP_i according to Eq. (13) (i stands for the ith cloud). Recognize the cloud which has the largest TP_i as typhoon cloud.

We verify this algorithm with typhoon Sepat satellite image which is obtained by FY-2C. The processing and results are shown in Fig. 3:

Fig.3 (a) are the preprocessing of satellite cloud images, (a1) is the original IR1 image of FY-2C at 23:30 on the 12th about Sepat, (a2) is the intercepted part of northwest pacific of (a1), (a3) is the fused image of 5-channel intercepted images, (a4) is the histogram of fused image, (a5) is enhanced image, and (a6) is the histogram of enhanced image. There are messy clouds in the satellite image, and non-typhoon cloud also has good roundness. It is difficult to identify typhoon from the image. Fig.3 (b) shows the histogram of Bezier curve before segmentation, Fig. 3 (c) is the curvature of the Bezier histogram curve. Fig.3 (d) is the gray image after the first segmentation, Fig.3 (e) is the Bezier histogram curve after the first segmentation, Fig.3 (f) shows the curvature of the Bezier histogram curve before the second division, Fig.3 (g) is the binary image after the second segmentation, Fig.3 (h) shows clouds tagged pseudo-color, Fig.3 (i) is the typhoon cloud. Fig.3 shows this algorithm can identify typhoon cloud and retain information of typhoon's main cloud.

3 RESULTS

We have made many experiments with 340 FY-2C satellite images (complete typhoon Sepat (20070812_1230—20070820_0100)). In order to certify the overall performance of the proposed method, we identify typhoon cloud with improved iterative area method based on Liu *et al.* (2001a) and the proposed method respectively. Iterative area method can not exclude non-typhoon Cloud, we improve this method as follows: Statistic the scope of typhoon cloud area [min, max], obtained the segmentation thresholds with Otsu method, iterative segmentation, remove part of background each segmentation, then use of gray level-gradient co-occurrence matrix (Jiang & Liu, 2004), statistic advantages of low gradient, average gray level, gradient inhomogeneity, which are obtained by secondary statistic, to extract texture information from the satellite cloud image (Liu *et al.*, 2001b). Combine roundness and texture information to identify typhoon cloud. The cloud that has even texture and its area within the scope of typhoon is identified as typhoon cloud. Compare improved iterative area method with proposed algorithm, results are shown in Fig. 4 and Table 1.

Fig. 4 shows identification results on different development stages of typhoon Sepat, such as generation period, maturity, extinction period, based on above methods. Fig. 4 (a) are results of one of generation period of typhoon cloud at 0 o'clock of 13th. Fig. 4 (a1) shows the original satellite image, and it is obvious that there are many clutter clouds. Fig. 4 (a2) shows identified result of improved iteration method, the method identifies the non-typhoon cloud which has good roundness as typhoon cloud. Fig. 4 (a3) is recognized result of the proposed method, it exclude the non-typhoon cloud of good roundness and close area, and identify typhoon cloud correctly. Fig.4 (b) are results of mature stage typhoon Sepat, at 3:00 on the 16th of the cloud and the recognition result, Fig.4 (b1) is original image of typhoon Sepat at 3 o'clock of 16th, there are messy cloud system compared with Fig. 4 (a1). Fig. 4 (b2) (b3) are results with improve iterative area method and our method. They all recognize the typhoon cloud. Comparatively speaking, our method extracted more integrity typhoon. Fig. 4 (c) shows result of extinction period. Fig. 4 (c1) is the original image of typhoon Sepat at 21 o'clock of 19th. Typhoon Cloud gradually spread at the period, Fig. 4 (c2) (c3) are results. From all these images, our method can obtain more complete typhoon cloud.

As can be seen from Table 1, the proposed method has higher recognition rate than improved iteration method at generation and extinction period of typhoon Sepat, where rotation feature plays a certain role. In theory, typhoon clouds all have rotation characteristics no matter in whatever developing stages. Recognition results of experiments are: In generating and extinction period, the recognition rate is far lower than that of maturity. Two main reasons are as follows:

(1) There are many messy clouds around typhoon cloud in generation period, and non-typhoon clouds connect to typhoon cloud closely. It is hard to disconnect them with single segmentation method. In addition, computing error of the rotation degree of typhoon cloud, some of non-typhoon clouds are identified as typhoon cloud. Eventually, the recognition rate of generation stage is low;

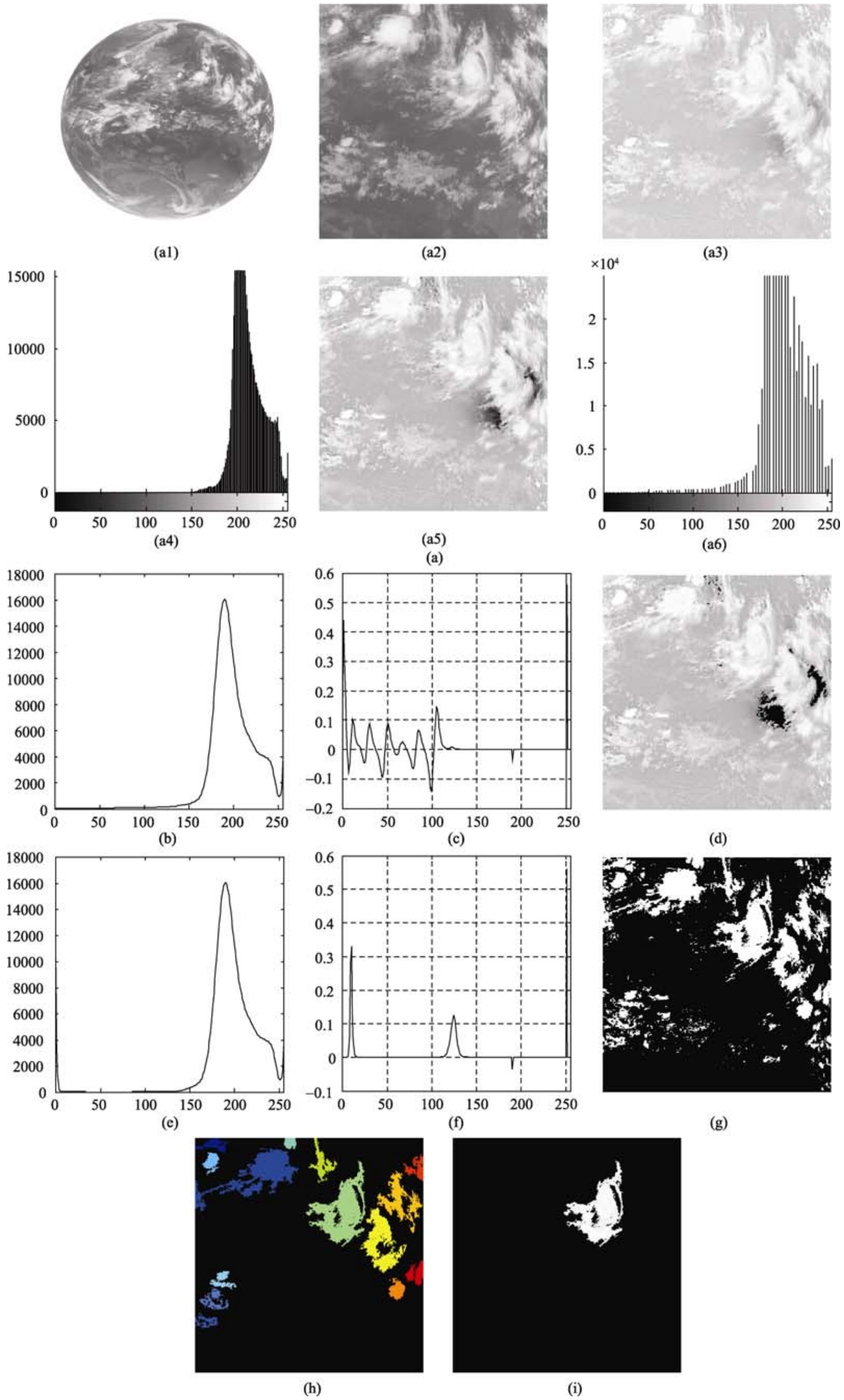

Fig. 3 Procedure of proposed method

(a) Pre-processing for satellite cloud image ((a1)Original image(20070812_2330IR1); (a2)Cropped IR1 image of northwest pacific;(a3)Fused image; (a4)Histogram of Fused image; (a5)Enhanced image; (a6)Histogram of enhanced image); (b) Bezier histogram before the first segmentation; (c) Curvature curve of Bezier histogram before the first segmentation; (d) Gray image after the first segmentation; (e) Bezier histogram after the first segmentation; (f) Curvature curve of Bezier histogram after the first segmentation; (g) Binary image of the second segmentation; (h) Pseudo-color of clouds; (i) Typhoon

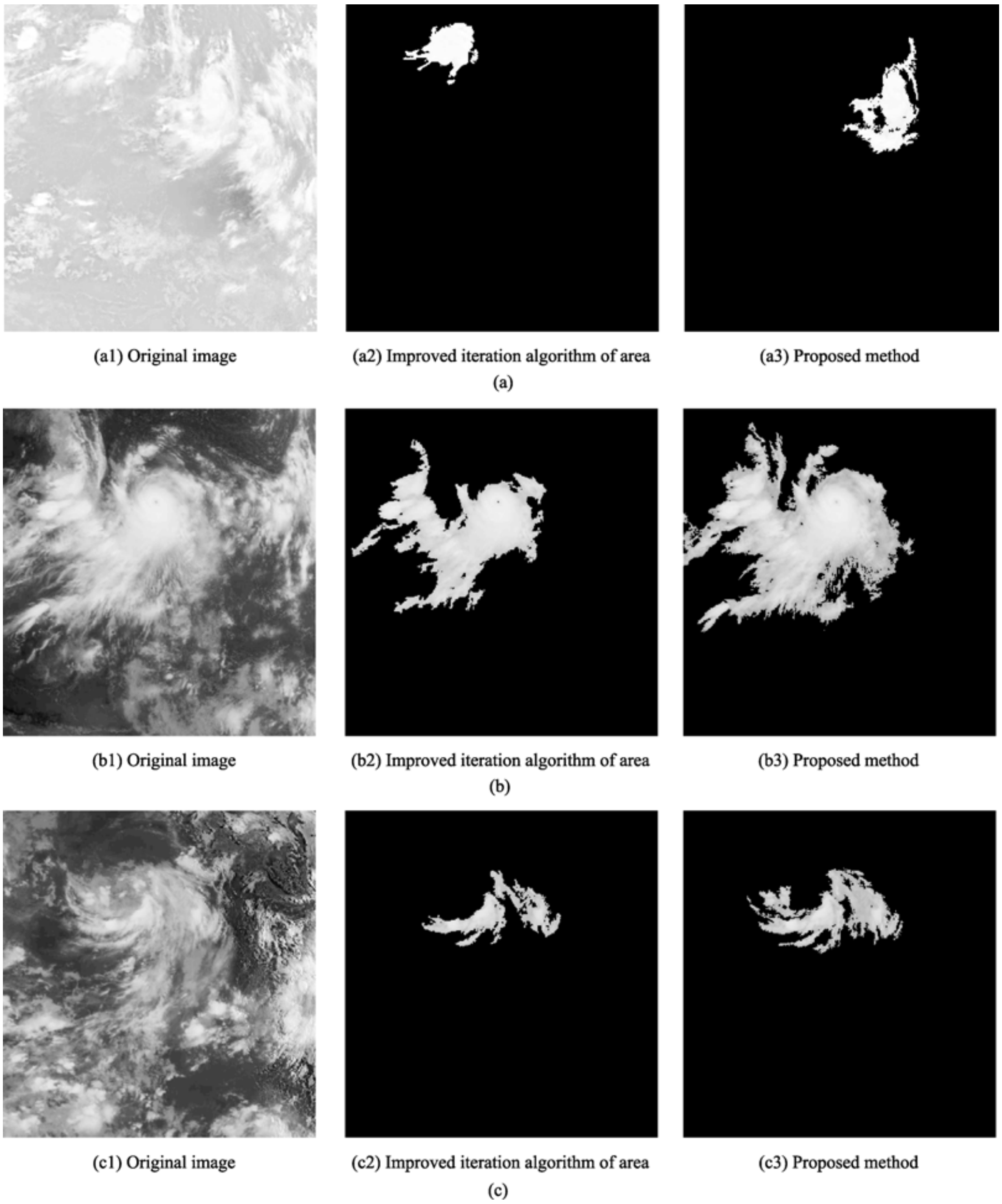

Fig. 4 Original cloud images and their recognition results
(a) Typhoon recognition (20070813_0000)((a1)Original image; (b) Typhoon recognition(20070816_0300); (c) Typhoon recognition (20070819_2100)

Table 1 Recognition results of typhoon in different development stages

Development stages (time)	Generation period (20070812_2330—20070814_2130)	Mature period (20070814_2200—20070818_0300)	Extinction period (20070818_0330—20070820_0100)	Total
Number of pictures	93	155	92	340
Improved iteration algorithm of area (identified/ recognition rate)	63/67.74%	150/96.77%	64/69.57%	277/81.47%
Proposed method (identified / recognition rate)	85/91.40%	153/98.71%	78/84.78%	316/92.94%

(2) In extinction stage, typhoon cloud always spread, location centroid is very difficult. Detecting convex - concave points often has error, and rotation degree also has error. In addition, the value that obtained by combining area and roundness of typhoon cloud is always too small. Therefore this will perhaps result in a high error rate.

In summary, recognition results shows the proposed method is simple, and has low computational complexity, twice segmentation based on curvature of the Bezier histogram curve retain complete information of typhoon main cloud, and get higher recognition rate. Location the center of rotation is still to be improved, defined centroid of the cloud as the center has some error to get convex - concave points and rotation degree, and then can not indentify typhoon cloud correctly sometimes.

4 CONCLUSION

Typhoon clouds all have the rotation characteristics. Based on this, we propose an algorithm that calculates rotation degree with statistic angles between edge clouds and the main cloud in single satellite image. We use curvature curve of Bezier histogram to obtain segmentation thresholds twice, iteratively segment the satellite image, and combine typhoon's geometric features, such as good rotation, larger area and good roundness to recognize the typhoon cloud. The proposed method is quite simple and has low computational complexity, practicality. It also needs to be improved: threshold segmentation can not disconnect non-typhoon clouds and typhoon cloud sometimes. In extinction stage, typhoon cloud always spread, location centroid is very difficult, it is not enough to define centroid as the center of rotation. If there are more than one typhoon cloud in a image, the algorithm identify only one and miss anther. Future research is mainly in choose more adaptive threshold and location the center of rotation, improve the recognition rate of different periods typhoon.

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利用边界特征自动识别台风云系

鲁 娟[1], 张长江[1,2,3], 张 翔[1], 杨 波[1], 端木春江[1]

1. 浙江师范大学 数理与信息工程学院, 浙江 金华 321004;

2. 中国科学院遥感应用研究所/北京师范大学遥感科学国家重点实验室, 北京 100101;

3. 中国气象科学研究院 灾害天气国家重点实验室, 北京 100081

摘 要: 基于台风无论是在生成期、成熟期, 还是在消亡期, 都具有螺旋性的特征, 非台风云系无此特征, 充分挖掘云系边界特点, 统计出单幅云图中各云系边界的旋转程度。运用 Bezier 直方图曲率曲线两次确定分割阈值, 迭代分割卫星云图, 结合台风的旋转与面积、形状等几何特性, 识别卫星云图中的台风云系。实验表明该方法对台风云系有很好的识别率。

关键词: 台风识别, 几何特性, Bezier 直方图, 曲率, 类圆度, 旋转

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1 引 言

台风云系正确识别是准确预报台风的前提。卫星云图中台风云系的识别具有一定的难度。卫星云图中云系的识别主要集中于利用云图的灰度、纹理和统计特征, 借助于神经网络、模糊技术、数学形态学和分形几何等数学工具进行识别(Vannoorenberghe & Flouzat, 2006; Ooi & Lim, 2006; Lopez 等, 2004; Intajag 等, 2006)。于波等(1996)利用数学形态学方法对台风云系进行区域分割, 统计台风云系纹理特征的概率密度, 结合模糊判别技术, 用 BP 神经网络对 GMS 云图的台风云系进行识别。刘凯等(2001a)建立迭代模型, 以使类间方差与类内方差的比值最大的灰度值为分割阈值, 多次迭代, 结合台风云系面积特征的分割方法, 分割台风; (2001b)利用图像的分形维数和灰度梯度共生矩阵提取卫星云图中台风密蔽云区等目标的纹理特性, 对卫星云图进行识别分类。王虹等(2008)结合台风主体云系具有灰度值较高、面积较大、活动范围有限和像元集中的特点, 综合采用阈值法、数学形态学和数理统计等方法, 对 FY-2C 气象卫星云图中的红外通道兰勃托(Lambert)原始投影云图中的台风分割进行了研究。郝玉龙等(2002)通过引入矢量矩的概念表征图像纹理整体分布规律, 采用全局搜索方式, 识别台风云系。上述方法是基于台风云系的某一特定的特征, 如纹理、形状等对台风云系进行识别的, 台风由于外部大气环流以及内部环流、水汽等差异的影响, 在不同阶段表现出不同的纹理、形状等特征, 上述基于某一特定特征的识别方法在识别不同阶段的台风上表现出较大的局限性。

本文基于台风无论是在生成期、成熟期, 还是在消亡期都具有螺旋性的特征, 挖掘台风云系边界信息, 统计出单幅云图中云系的旋转程度。运用 Bezier 直方图曲率曲线两次确定分割阈值, 迭代分割卫星云图, 结合台风的旋转与面积、形状等几何特性, 识别卫星云图中的台风云系。实验表明该方

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第一作者简介: 鲁 娟(1985—), 女, 浙江开化人, 浙江师范大学在读硕士研究生, 主要研究卫星云图处理, 发表论文 3 篇。E-mail: lujuan104@163.com。

通讯作者: 张长江, E-mail: zcj74922@zjnu.cn。

法对台风云系识别率较高。

2 算法描述

2.1 算法原理

台风是热带洋面上气旋性扰动发展而成的低气压系统，在北半球台风周围的气流绕中心逆时针方向旋转，在南半球则相反。台风发生、发展、成熟、消亡的过程中，表现出不同纹理、形状等特征，比较难以用某一特定形态去识别。与其他云系相比，台风有其特殊的云系特征：一般来说，台风主体云区直径至少要达 150km，有较好的类圆性；无论处于发展的哪个阶段，台风云系是一个“有组织”的整体；台风中心云区有较大的吸附力，其周边的云系绕该中心旋转，即使在台风的消亡阶段，台风云系破碎，仍具有大致的涡旋结构。基于以上特性能剔除面积较小的云系及一部分带状云系，并且能用旋转这一特性区别开台风与绝大部分云系。云导风能描述出台风的旋转特性，用云导风识别卫星云图上的台风也存在不足：一方面，连续时段的多幅云图才能描绘出云导风，在单幅云图台风云系的识别上不适用；另一方面，即使云导风图描绘出来了，如何自动判断旋转仍然是大问题。本文基于单幅云图中台风云系边缘或多或少能体现旋转特征这一特点，挖掘边缘云系信息，统计云系的旋转程度，进而结合类圆性等其他特征识别台风。在实现过程中自动选取分割卫星云图中各个云系的灰度阈值十分重要，直接影响到后续识别的正确率。

2.2 云图分割的灰度阈值选取

灰度阈值的确定直接影响云系的分割结果及台风主体云系信息保留的完整程度。卫星云图中背景复杂，目标的灰度分布不均匀，如何选取一个自适应阈值是台风主体云系识别的重点之一。目前阈值的选取方法很多，简单的阈值选取方法如迭代法、最大熵阈值法、聚类算法等能取得较好的阈值，不过其只对部分图像有效。基于原始云图中各个云系结构相同部分灰度比较相近，台风云系更是具有像元集中、灰度较高的特点，对应在直方图中相似部分灰度比较集中，大部分能形成特定的波峰。综观上述特点，本文利用文献(金梅等，2004)中的 Bezier 直方图曲率曲线选取灰度阈值。Bezier 曲线的两个位置坐标的参数方程表示如下：

$$x(t)=\sum_{k=0}^{L-1} x_k B_{k,L-1}(t) \tag{1}$$

$$y(t)=\sum_{k=0}^{L-1} y_k B_{k,L-1}(t) \tag{2}$$

式中原始图像被量化成 L 个灰度级，$(x_k,\ y_k)$，$k=0,1,2,\cdots,L-1$ 是灰度直方图中各个控制点的位置，$0\leqslant t\leqslant 1$，$B_{k,L-1}(t)$是 Bezier 曲线上各点位置矢量的调和函数，其表达式为：

$$B_{k,L-1}(t)=\frac{(L-1)!}{k!(L-k-1)!}t^k(1-t)^{L-k-1} \tag{3}$$

由参数方程表示的 Bezier 直方图在每一个控制点处的曲率 Cur(t)可利用下式求解：

$$\mathrm{Cur}(t)=\frac{x'(t)y''(t)-y'(t)x''(t)}{(x'(t)^2+y'(t)^2)^{3/2}} \tag{4}$$

式中，$x'(t)$, $y'(t)$表示一阶导数；$x''(t)$, $y''(t)$表示二阶导数。利用以下的差分方程求解式(4)中用到的一阶导数和二阶导数：

$$\begin{cases} x'(t)=1/2[x(t+1)-x(t-1)] \\ y'(t)=1/2[y(t+1)-y(t-1)] \end{cases} \tag{5}$$

$$\begin{cases} x''(t)=x(t+1)-2x(t)+x(t-1) \\ y''(t)=y(t+1)-2y(t)+y(t-1) \end{cases} \tag{6}$$

根据台风云系的实际特点，本文取 Bezier 直方图曲率曲线的峰点，这些峰点对应直方图曲线变化剧烈处，实验证明以其中的某个峰点对应的灰度值为阈值能分开一部分云系，但适应性不好。例如，对某一幅云图，取第 3 个峰点对应的灰度值为阈值能很好地分割出各个云系与背景，另一幅云图就需要取第 5 个峰点对应的灰度值为阈值才能将背景与云系很好地区分开；另外，原始卫星云图的对比度情况也对分割结果有较大的影响。为提高分割阈值的自适应性，本文先对原始卫星云图进行增强预处理，然后对增强后卫星云图进行分段线性拉伸。该过程能增强卫星云图的对比度，提高后续二值化阈值选取的自适应性。

2.3 台风云系识别准则

台风云系一般具有较大的面积，亮的灰度值，还有一定的类圆性，可以用类圆度与面积结合作为其中的一个判定台风云系的准则。由文献(余建波，2008)得到类圆度公式：

$$Y=\frac{4\pi A}{C^2} \tag{7}$$

式中，A 表示云系面积，C 表示云系的周长。

由于云系为一不规则的几何体，其边缘细节过多，这时会使边缘周长 C 过大，从而导致类圆性较好但边缘细节过多的云系 Y 值过小，若仅用类圆度公式计算，效果很不理想。本文利用台风云系面积较大特征将判定准则改进为类圆度与面积的乘积：

$$K = Y \times A^{1.8} \tag{8}$$

另外一个特征量是台风云系的旋转程度。单幅云图中旋转信息体现在台风云系边缘上，如图 1 所示:

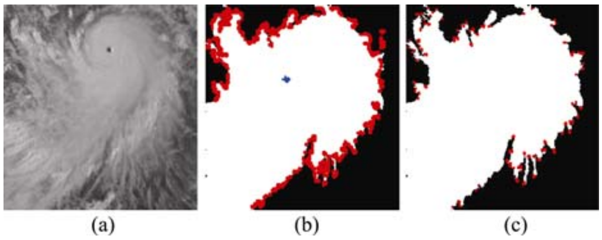


图 1　单幅云图上的旋转信息

(a) 截取的台风云图; (b) 云系的角点与质心点; (c)云系的凹凸点

图 1(a)是一幅 2007-08-16 8 时第 9 号台风 Sepat 融合后的台风主体云系截取图，螺旋线信息丰富。从单幅图像中可以看出台风边缘云系绕着中心转，这些边缘云系与密闭云区之间的夹角沿逆时针计算绝大多数是锐角。比较非台风云系，此夹角大小没有该特性。综观发生在各个时期的台风，结合台风云图的涡旋性，可以得到统计出台风云系边缘的凸点与主体的夹角就能大致表示出台风的旋转程度，区别出台风云系和其他大部分的非台风云系。具体计算方法如下:

(1) 对云系二值化，去掉断开的散云，填充密闭区域的空洞，避免检测出云系内部边缘角点。

(2) 用 Harris 算法检测云系边缘上的角点，即在每个像元点计算 2×2 自相关矩阵:

$$G = w\left|(\nabla I)(\nabla I)^{\mathrm{T}}\right| \tag{9}$$

$$H = \det(G) - h(\mathrm{trace}(G))^2 \tag{10}$$

式中, w 是高斯平滑模版, h 是给定的常量 0.04，若 H 足够大，就把该像元检测为角点。

(3) 求出云系边缘的凹点与凸点，方法如下: 计算出云系质心 a，将上步中得到的角点按逆时针排列，得到逆时针角点序列 J_i，i=1,2,⋯,n; n 为角点的个数。计算出各个角点与质心的距离 d_i; 由式(11)得到相邻距离间的差值Δd_i

$$\Delta d_i = \begin{cases} d_i - d_{i-1}, 2 \leqslant i \leqslant n \\ d_i - d_n, \quad i = 1 \end{cases} \tag{11}$$

检测出Δd_i，i=1,2,⋯,n 的跳变点，若Δd_i 从正跳变到负则将点 i 存为凹点; Δd_i 从负跳变到正则将点 i 存为凸点。图 1(b)中红点是用 Harris 算法检测出的边缘角点，蓝色的*点是该云系的质心，结合云系质心点与边缘角点及区域的连通性我们可以大致定出图像边缘凹凸点，如图 1(c)。

(4) 计算凸点与主体云系的夹角: 以相邻两凹点为端点画有向线段 $\overline{AB}$, (A, B 按逆时针顺序排列)，求出 $\overline{AB}$ 的中点 C 坐标，连接夹在 A、B 两凹点间的凸点 D 与中点 C，做直线 DC，计算 DC 与 $\overline{AB}$ 的夹角 θ_i。

(5) 统计所有的夹角θ中锐角所占的比例，称该比例为旋转程度 Z，若旋转程度超过 80%就可以将该云系判断成具有旋转特性的云系。在北半球台风的识别以锐角计算旋转程度，南半球的台风识别则以钝角计算旋转程度。(卫星云图中包含纬度信息，根据云图即能自动识别出南北半球。)

理论上，全为锐角或全为钝角才判断成具有旋转特性的云系，由于云图的二值化处理会造成部分边缘缺失或不完整，判断凹凸点时也有部分误差，所以本文以 80%为判断的界限。

综合上述台风面积、类圆度、旋转特性等特征量，得出式(13)用于识别台风云系。TP 值最大的云系即是台风主体云系。

$$R = \begin{cases} Z, Z > 80\% \\ 0, Z \leqslant 80\% \end{cases} \tag{12}$$

$$\mathrm{TP} = KR \tag{13}$$

2.4　算法实现

本文算法流程如图 2。

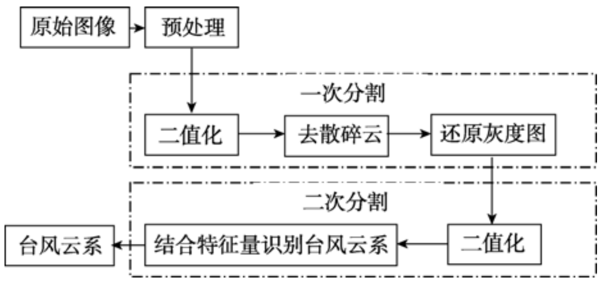


图 2　本文算法实现流程图

2.4.1　云图预处理

预处理包括 3 部分:

(1) 截取特定区域卫星云图。FY-2C 得到的是全球范围的云图，若直接用本文方法处理，计算量大。基于台风活动区域较小，本次试验从原始图中截取西北太平洋部分台风活动区域(大小为 800×800)进行处理。

(2) 融合多通道的卫星云图。为了充分利用多通道卫星云图的有用信息，综合各个通道云图的优势，得到台风云系的完整信息，在卫星云图融合方面已经做了大量的前期工作。本文用非下采样 Contourlet 变换结合能量原则的方法融合 FY-2C 5 个通道的卫

星云图, 得到融合后的云图, 用于后续处理。关于云图融合的方法详见文献(Lu 等, 2009)。

(3) 增强云图。提高后续处理中二值化阈值选取的自适应性, 需要对融合后的云图进行增强处理(陈帅, 2006)。考虑到 Symmlet 系列小波具有近似对称性, 取 sym4 进行 2 层分解, 增强各个方向的高频细节。小波增强后对细节增强后的云图进行分段线性拉伸。

2.4.2 云图分割

一次分割往往不能很好地分开各个云系, 本文中采用二次分割法, 分离出台风云系。第一次分割根据前述选取灰度阈值的方法按式(14)选取分割阈值:

$$T_1 = \frac{P_1(\mathrm{int}(0.6N)) + P_1(\mathrm{int}(0.7N))}{2} \tag{14}$$

式中, N 是 Bezier 直方图曲率曲线的峰值点个数, int 表示取整数, $P_1(N)$是第一次分割前图像 Bezier 直方图曲率曲线上第 N 点的峰值对应的灰度值。

第一次分割选取一个粗糙的阈值, 仅用面积特征判断, 去除部分背景及面积较小的独立云系, 而后恢复成灰度图像, 进行第二次分割。重新计算一次分割后图像的 Bezier 直方图曲率曲线。综合考虑阈值能否较好地区分开云系与背景, 断开云系之间的连接及云系信息保留的完整度, 最终选定第二次分割阈值如式(15)。

$$T_2 = \frac{2P_2(\mathrm{int}(0.6N)) + P_2(\mathrm{int}(0.7N))}{3} \tag{15}$$

式中, $P_2(N)$是第一次分割后图像 Bezier 直方图曲率曲线上第 N 点的峰值对应的灰度值。

根据上式进行云系分割, 得到各个独立云系, 用伪彩色标记不同云系, 分别计算这些云系的面积、周长、类圆度及旋转程度, 根据式(13)计算出 TP_i(i 表示第 i 个云系)。将 TP_i 按从大到小排列, 取出 TP 值最大云系, 识别为台风云系。

下面以 FY-2C 发回的 2007 年第 9 号台风 Sepat 的卫星云图为例来验证本文的算法, 具体过程和效果如图 3。

图 3(a)所示为预处理部分的图像, 其中图 3(a1)是 FY-2C 发回的 12 日 23 点 30 分 Sepat 刚形成时红外一通道的原始云图, 图 3(a2)是截出该时间段西北太平洋部分区域的 IR1 通道云图, 图 3(a3)则是 FY-2C 五个通道融合后的图像, 图 3(a4)是增强前图像直方图, 图 3(a5)是增强后图像, 图 3(a6)是增强处理后图像直方图。从图中可以看出该时刻台风云系周边杂乱云系较多, 并且云图中也有类圆性好的非台风云系, 识别台风有一定困难。图 3(b)为一次分割前的 Bezier 直方图曲线, 图 3(c)是一次分割前的 Bezier 直方图曲率曲线, 图 3(d)是一次分割后的灰度图像, 图 3(e)是一次分割后, 即二次分割前的灰度图像 Bezier 直方图曲线, 图 3(f)为二次分割前的灰度图像 Bezier 直方图曲率曲线, 图 3(g)为二次分割后二值图像, 图 3(h)是用伪彩色标记各个独立云系的图像, 图 3(i)识别出的台风云系, 从图中看出本文算法能较好地自动识别出台风云系, 保留台风主体云系相关信息。

3 实验结果

用 FY-2C 卫星获得的自 2007-08-12 23 时 30 分形成到 2007-08-20 1 时消亡的完整 Sepat 340 幅云图进行实验, 分别用基于刘凯等(2001a)迭代面积的改进方法与本文算法进行识别。由于迭代面积法分割台风云系时往往不能将非台风云系剔除, 现将迭代面积法改进如下: 根据实验统计出台风面积范围[min, max], 用使类间方差与类内方差比值最大的灰度值作为门限, 迭代分割卫星云图, 每次迭代去部分背景, 而后利用灰度梯度共生矩阵(姜青香 & 刘慧平, 2004), 统计小梯度优势、平均灰度、梯度不均匀性 3 个二次统计特征, 提取各云系的纹理信息(刘凯等, 2001b)。结合类圆度与纹理信息判断留下的云系。将面积在台风面积范围之内且类圆度高、纹理信息均匀的云系识别为台风云系。比较改进的迭代面积法与本文算法, 结果如图 4 和表 1。图 4 为分别用改进的迭代面积法、本文算法识别 Sepat 生成初期、成熟期、消亡期各阶段部分云图结果。其中图 4(a)组图分别是 13 日 0 时台风生成期云图及识别结果。其中图(a1)是原始云图, 该图为台风形成初期的云图, 杂乱云系较多, 图 4(a2)是用改进的迭代面积法识别出的台风云系, 该方法可能将类圆度高的非台风云系识别成台风云系, 图 4(a3)为本文方法识别结果, 排除了类圆度高, 面积相近的非台风云系的干扰, 正确地识别出台风云系。图 4(b)组图是 2007-08-16 3 时 Sepat 成熟阶段的云图及识别结果, 图 4(b1)为原始云图, 从图中可以看出成熟时期的杂乱云系少, 台风云系类圆度高, 云系完整, 图 4(b2)(b3)分别是用改进迭代面积法和本文方法识别出的结果, 相对而言, 本文方法提取的台风主体云系稍完整。图 4(c)组是 2007-08-19 21 时 Sepat 消亡期的云图识别, 图 4(c1)是该时刻的原始图像, 消亡期台风云系渐渐散开, 图 4(c2)(c3)分别为改进迭代面积法和本文方法识别的结果, 由图中可以看出, 两种方法均正确识别出该时刻的台风云系, 本文方法得到的云系保留得更完整。

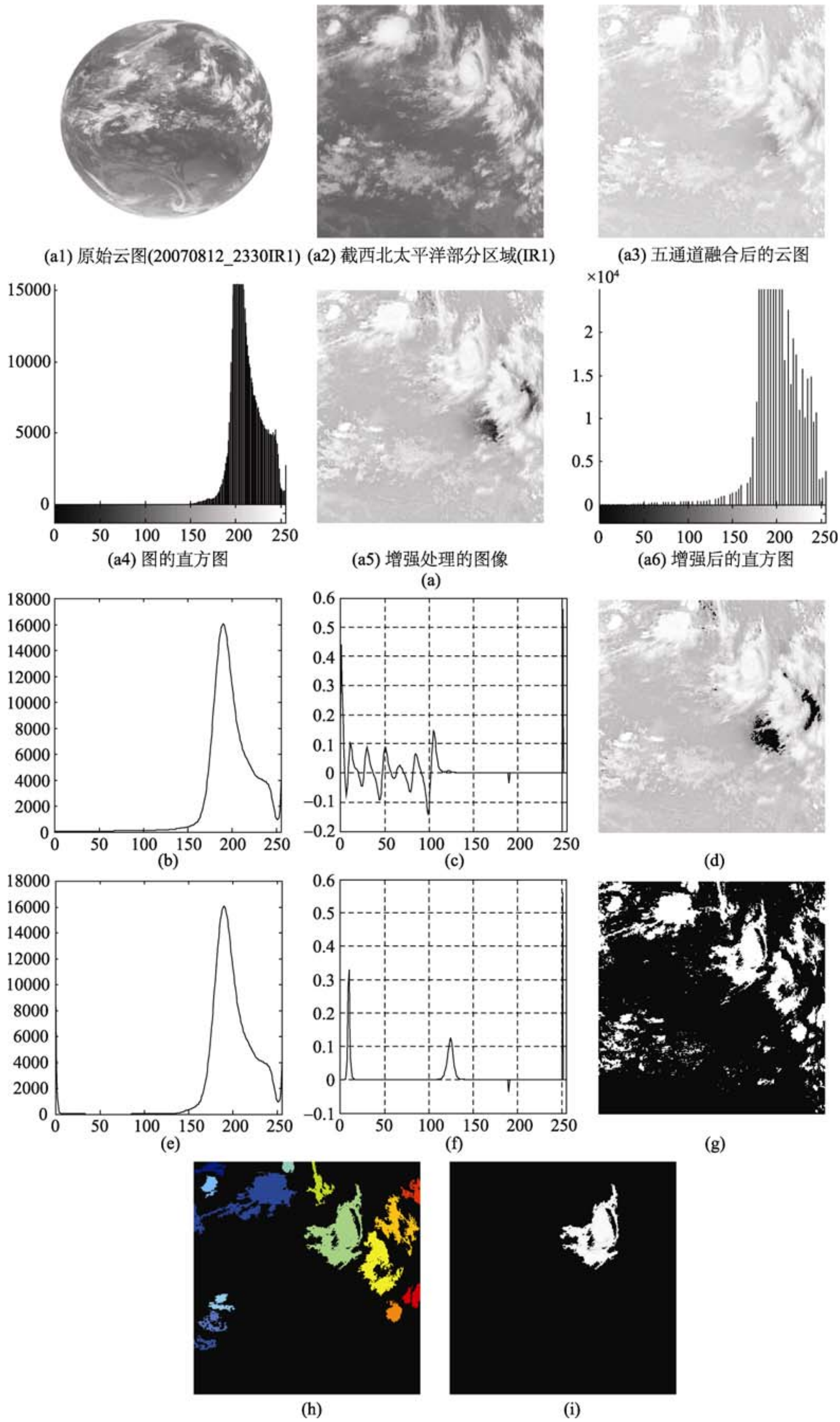
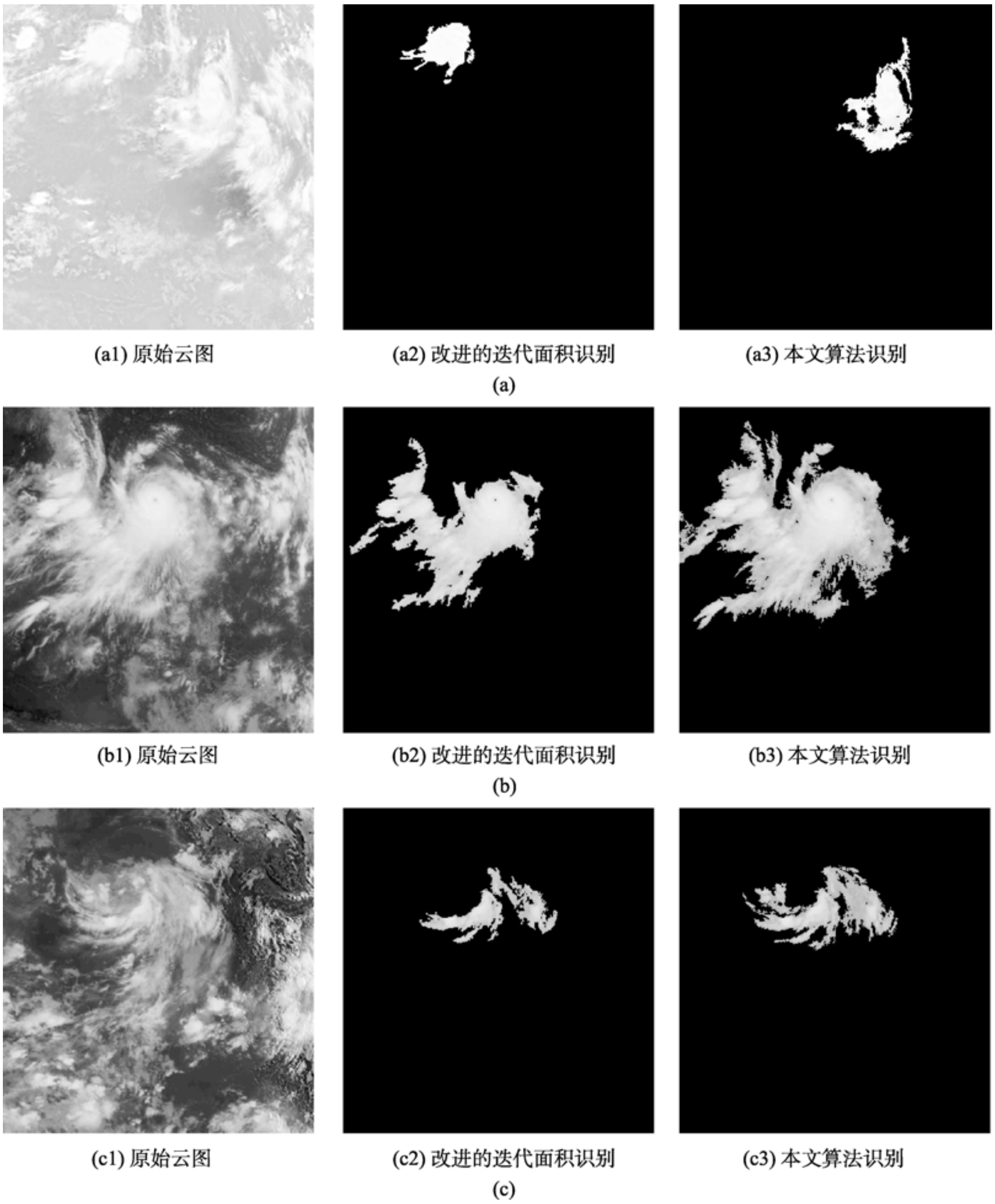


图 3 本文算法处理过程

(a) 预处理部分图像; (b) 一次分割前的 Bezier 直方图; (c) 一次分割前的 Bezier 直方图曲率曲线; (d) 一次分割后的灰度图像; (e) 一次分割后的 Bezier 直方图; (f) 一次分割后 Bezier 直方图曲率曲线; (g) 二次分割的二值图像; (h) 伪彩色标记各云系; (i) 台风云系



(a1) 原始云图 (a2) 改进的迭代面积识别 (a3) 本文算法识别
(a)

(b1) 原始云图 (b2) 改进的迭代面积识别 (b3) 本文算法识别
(b)

(c1) 原始云图 (c2) 改进的迭代面积识别 (c3) 本文算法识别
(c)

图 4 原始云图及其识别结果

(a) 台风云系识别(20070813_0000); (b) 台风云系识别(20070816_0300); (c) 台风云系识别(20070819_2100)

表 1 台风各阶段云系识别结果

发展阶段(时间段)	生成期(20070812_2330—20070814_2130)	成熟期(20070814_2200—20070818_0300)	消亡期(20070818_0330—20070820_0100)	合计
样本数	93	155	92	340
改进的迭代面积法(识别正确数/识别率)	63/67.74%	150/96.77%	64/69.57%	277/81.47%
本文方法(识别正确数/识别率)	85/91.40%	153/98.71%	78/84.78%	316/92.94%

从表 1 中可以看出本文方法对处在生成阶段及消亡阶段的台风识别率明显高于改进的迭代面积法, 旋转特性的提取起到一定的效果。理论上, 台风无论处在发展的哪个阶段, 都具有旋转特性, 实验中得出的识别结果却是: 生成期及消亡期台风的识别率远远低于成熟期的台风, 分析原因, 主要有以下两个:

(1) 生成阶段的台风云系杂乱云系较多, 台风云系与非台风云系连接紧密的情况下, 二值化难将其断开, 从而导致台风云系旋转程度计算出错, 部分非台风云系被误认成台风云系, 最终导致生成阶段台风云系识别率不高。

(2) 在台风的消亡阶段, 台风云系渐渐散开, 质心定位相当困难, 云系边缘凹凸点往往判断出错,

影响旋转程度的判断, 并且该阶段台风云系面积与类圆度的乘积过小, 造成识别不出完整台风云系, 出错率较高。

综上所述, 从识别结果可以总结出本文方法简单, 计算量小, Bezier 直方图曲率曲线二次分割保留较完整的台风云系信息, 识别率较高, 但在旋转中心的选定上仍需要改进, 仅仅以云系的质心为相对中心提取凹凸点造成台风消亡期识别率不高。

我们也用该方法提取 NOAAH,TERRA 等其他遥感卫星上的台风云系, 实验证明, 应用于不同的卫星, Bezier 直方图曲率曲线二次分割阈值需做相应的调整, 此外, 应用该方法能较好地提取出不同遥感卫星中的台风主体云系。

4　结　论

本文基于台风云系旋转的特性, 提出在单幅图像中用边界云与中心主体云夹角来统计旋转程度, 运用 Bezier 直方图曲率曲线两次确定分割阈值, 分割卫星云图, 结合台风云系面积较大, 类圆性较好, 旋转程度高的特点, 识别台风云系。该算法计算量小, 识别率高, 具有一定的实用性。但是也存在以下问题: 灰度阈值分割导致台风生成阶段仍有部分非台风云系与台风云系分不开; 台风消亡阶段云系散开, 台风云系分成各个独立的小云系, 质心定位困难, 此时仅用云系边界信息来描述旋转特性仍然不够, 导致识别出的只是部分台风云系; 只能识别出单个台风, 假如存在双台风或者是多台风, 本文方法会漏识。后续研究工作主要在二值化自适应阈值的选择及单幅云图如何确定旋转中心, 更确切的描述旋转特性, 提高台风主体云系的自动识别率。

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