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Extraction Method for Earthquake-Collapsed Building Information Based on High-Resolution Remote Sensing

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Abstract. At present, the extraction of earthquake disaster information from remote sensing data relies on visual interpretation. However, this technique cannot effectively and quickly obtain precise and efficient information for earthquake relief and emergency management. Collapsed buildings in the town of Zipingpu after the Wenchuan earthquake were used as a case study to validate two kinds of rapid extraction methods for earthquake-collapsed building information based on pixel-oriented and object-oriented theories. The pixel-oriented method is based on multi-layer regional segments that embody the core layers and segments of the object-oriented method. The key idea is to mask layer by layer all image information, including that on the collapsed buildings. Compared with traditional techniques, the pixel-oriented method is innovative because it allows considerably rapid computer processing. As for the object-oriented method, a multi-scale segment algorithm was applied to build a three-layer hierarchy. By analyzing the spectrum, texture, shape, location, and context of individual object classes in different layers, the fuzzy determined rule system was established for the extraction of earthquake-collapsed building information. We compared the two sets of results using three variables: precision assessment, visual effect, and principle. Both methods can extract earthquake-collapsed building information quickly and accurately. The object-oriented method successfully overcomes the pepper salt noise caused by the spectral diversity of high-resolution remote sensing data and solves the problem of same object, different spectrums and that of same spectrum, different objects. With an overall accuracy of 90.38%, the method achieves more scientific and accurate results compared with the pixel-oriented method (76.84%). The object-oriented image analysis method can be extensively applied in the extraction of earthquake disaster information based on high-resolution remote sensing.

1. Introduction

Building collapse (damage) during earthquakes directly affects people's lives and properties and thus generates essential information on earthquake catastrophes. More than 80% of casualties due to urban

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earthquakes are caused by building collapse, which has consequently become an important indication of seismic damage. Obtaining earthquake-collapsed building information quickly and accurately is important in the earthquake relief, emergency management, command decision, and post-disaster reconstruction efforts of state and local governments.

With the development of high-resolution remote sensing technology, the extraction of earthquake-collapsed building information has become a hot research topic, for which scholars from various countries have carried out relevant research work. Such studies are mainly categorized into two in terms of research content: qualitative classification [1–3], which involves extracting and classifying earthquake-collapsed building information; and quantitative assessment [4–6], which involves building a quantitative analysis model and assessing collapsed buildings by using relevant evaluation criteria. The majority of existing studies is still at the early stages of exploration and is mainly focused on qualitative classification and quantitative assessment.

Influenced by the uncertainties of remote sensing data and the complexities of the characteristics of seismic damage [7], the extraction and classification of seismic damage information remains dependent on artificial visual interpretation and has yet to meet the demands of earthquake relief and emergency management. Considering the features of high-resolution remote sensing as well as the earthquake-collapsed buildings in the town of Zipingpu after the Wenchuan earthquake, this study investigates two rapid extraction methods based on pixel-oriented and object-oriented theories. The results of the two methods are analyzed from three aspects, namely, extraction precision, visual effect, and principle.

2. Theory

The object-oriented remote sensing classification method is based on the characteristics of high-resolution remote sensing images and was first proposed by Baatz and Schape [8]. Its core techniques are multi-scale segmentation (object generation) based on the principle of minimum heterogeneity and fuzzy mathematical analysis (information extraction) based on the fuzzy logic classification system [9]. The basic process is as follows. First, the image is segmented to generate objects with the homogenous pixels. The characteristics of the different object types, including spectrum, shape, texture, shadow, and spatial position, are then analyzed. Finally, the fuzzy determined rule for extraction and classification is established.

The eigenfunctions applied in this paper are as follows [10]:

- Length/width. It represents the ratio of the length and width. The formula is shown in Eq. (1), where $eig(S)$ is the eigenvalue of the covariance matrix, S is the covariance matrix of the object, ω is the width of the object, and l is the length of the object.

$$\gamma = \frac{l}{\omega} = \frac{eig_1(S)}{eig_2(S)}, eig_1(S) > eig_2(S) \quad (1)$$

- Grey Level Concurrence Matrix (GLCM) Homogeneity. It reflects the texture homogeneity of the object. A high GLCM homogeneity value indicates strong texture homogeneity. The formula is as follows:

$$\sum_{i,j=0}^{N-1} \frac{p_{i,j}}{1+(i-j)^2}, \quad (2)$$

where i is the row number, j is the column number, $p_{i,j}$ is the standardization value of i rows and j columns, and N is the total number of rows or columns with a range of [0, 90].

- Shape index. It reflects the boundary smoothness of a polygonal object. The formula is as follows:

$$\frac{b_v}{4\sqrt{p_v}}, \quad (3)$$

where b_v represents the circumference of the object, and p_v represents its area with a range of [1, ∞]. A regular boundary represents a small shape index value, and vice versa. When the boundary is square, the shape index becomes 1.

- Grey Level Difference Vector (GLDV) Contrast. It reflects the changing variance between the object and its surrounding objects. The formula is as follows:

$$\sum_{k=o}^{N-1} V_k k^2 , \tag{4}$$

where i is the row number, j is the column number, $p_{i,j}$ is the standardization value of i rows and j columns, *k* is the object, and N is the total number of rows or columns.

- GLCM Entropy. It is expressed as

$$\sum_{i,j=0}^{N-1} p_{i,j}(-\ln p_{i,j}) , \tag{5}$$

where i is the row number, j is the column number, $p_{i,j}$ is the standardization value of i rows and j columns, and N is the total number of rows or columns with a range of [0, 90]. A uniform object texture indicates large GLCM entropy, and vice versa.

3. Methodology

3.1. Data

The Wenchuan earthquake is the most destructive earthquake since the founding of New China. In this study, the town of Zipingpu in Dujiangyan City served as the research area. This town lies in the west edge of the West Sichuan Plain, the northwest of Dujiangyan City, and only 2 km away from the urban center. It covers an area of approximately 50.2 km^2 and comprises a population of 18,075. The annual average temperature and the annual rainfall are 15 °C and 1260 mm, respectively. The forest coverage rate is 60%.

The data used in this study included the pre-seismic IKONOS image of March 16, 2008 (four wavebands, spatial resolution of 1 m), the post-seismic QUICKBIRD image of September 1, 2008 (four wavebands, spatial resolution of 0.6 m), a 1:50000 digital elevation model, and the land use map before the earthquake.

3.2. Pixel-oriented extraction method

The temporary house used in the study was not an earthquake-collapsed building but a new kind of post-seismic ground object class that closely represented earthquake information. Nevertheless, the object was still used in this study as part of the earthquake-collapsed building scope.

Following the pixel-oriented method, we employed an indirect extraction method based on “multi-layer regional segmentation.” In this case, all the non-damaged building information was treated as the environmental background and would be removed layer by layer until only the earthquake-collapsed building information remained. The specific processes of this method are shown in Table 1.

The land use map was used to segment the urban construction land. Then, the binary image of earthquake disaster information was utilized to extract earthquake-damaged building information for urban construction. The enhanced vegetation index (EVI) was introduced to separate the information on the temporary house from that on the earthquake-damaged buildings because it is highly sensitive to green vegetation and can effectively eliminate the effect of soil background [11]. The EVI is expressed as

$$EVI = 2.5 * \frac{R_{nir} - R_{red}}{R_{nir} + 6 * R_{red} - 7.5 * R_{blue} + 1} , \tag{6}$$

where R_{nir}, R_{red}, and R_{blue} respectively denote the reflectivities of the near-infrared band, red band, and blue band of the visible light.

Table 1. The extraction process of the pixel-oriented method

First segmentation	Second segmentation	Third segmentation
Urban construction land (reserved)	Earthquake-damaged building information for urban construction (reserved)	Temporary house (EVI ≥ 0.4)
		Earthquake-collapsed buildings (EVI < 0.4)
	Non-damaged building information (removed)	
Non-urban construction land (removed)		

3.3. Object-oriented extraction method

The object-oriented method was performed using the Definiens Developer 8.0 software. The classification hierarchy and fuzzy classification rule of each layer are shown in Table 2.

Table 2 The extraction process of the object-oriented method

First classification (scale 100)	Second classification (scale 80)	Third classification (scale 48)
Unclassified	Unclassified	Collapsed buildings (shape index ＞2.8; GLDV contrast ＞ 780; GLCM entropy ≤ 4.1)
		The remaining were unclassified.
	Temporary dwellings (length/width ≥ 1.28; brightness ＞ 290; GLCM homogeneity ＞ 0.18)	
Vegetation and water body (NDVI ≥ 0.5, NDVI ≤ 0.06)		

The entire extraction process was divided into three layers, and different segment scales were adopted based on the characteristics of the different target objects. The eigenfunctions of length/width, GLCM homogeneity, shape index, GLDV contrast, and GLCM entropy were selected to establish the fuzzy determined rules.

4. Result and Discussion

4.1. Extraction result

The results of the pixel-oriented extraction are shown in Figures 1 and 2; the extraction results for the temporary house are provided in the former, where the blue regions represent the temporary houses; whereas those for the collapsed building are presented in the latter, where the red regions represent the earthquake-collapsed buildings.

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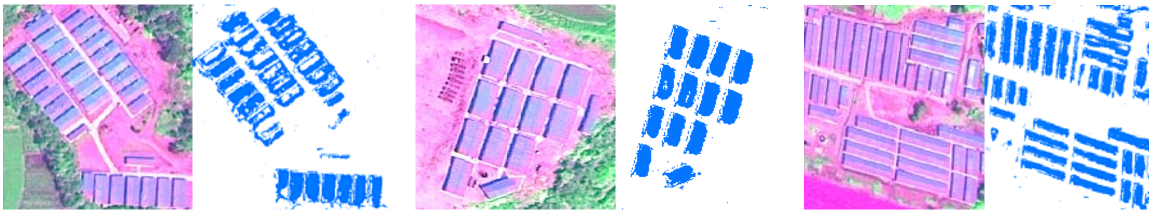

Figure 1. The extraction result for the temporary houses

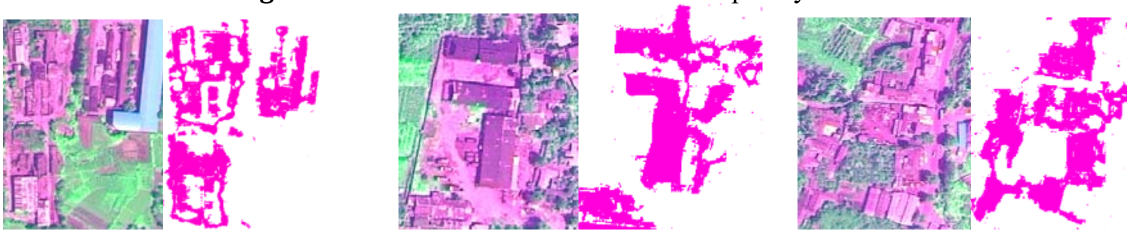

Figure 2. The extraction result for the collapsed buildings

The results of the object-oriented extraction are shown in Figures 3 and 4; the extraction results for the temporary houses are provided in the former, where the green regions represent the temporary houses; whereas those for the collapsed buildings are presented in the latter, where the red regions represent the earthquake-collapsed buildings.

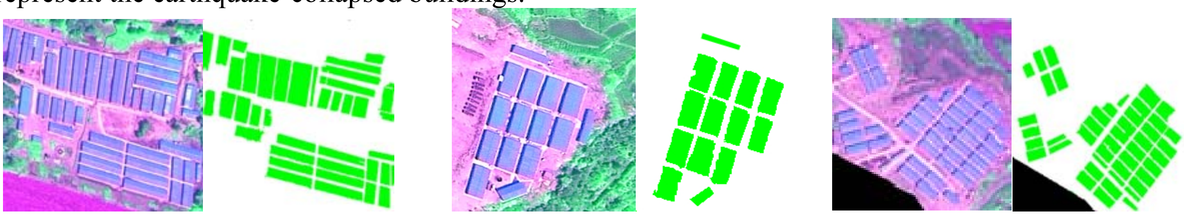

Figure 3. The extraction result for the temporary houses

Figure 4. The extraction result for the collapsed buildings

4.2. Analysis and discussion

The two methods were comprehensively compared and analyzed from three aspects: extraction precision, visual effect, and principle.

1. Extraction precision

The results of the accuracy evaluation are shown in Table 3. The overall accuracy of the object-oriented information extraction method is 90.38%, with a Kappa coefficient of 0.8684; whereas that of the pixel-oriented information extraction method is 76.84%, with a Kappa coefficient of 0.7269. The extraction accuracy of the object-oriented method is significantly higher than that of the pixel-oriented method.

Table 3. The accuracy evaluation of the two methods

	Producer accuracy	User accuracy	Overall accuracy	Kappa coefficient
Pixel-oriented method	82.81%	80.66%	76.84%	0.7269
Object-oriented method	94.23%	92.67%	90.38%	0.8684

2．Visual effect

As shown in the results of the pixel-oriented extraction method (Figures 1 and 2), the classified map comprises numerous noises and voids. This condition results in the so-called "pepper salt phenomenon," wherein many pixel points are not correctly classified, thereby resulting in a low extraction accuracy. The edge of the extracted object class is rough, which not only influences the visual effect but also reduces the extraction accuracy to some extent.

The results of the object-oriented extraction method (Figures 3 and 4) obviously demonstrate enhanced visual effect with a smooth edge, no voids, and little noise. Therefore, this method effectively avoids the pepper salt phenomenon and provides extraction results that match the visual requirements of human eyes. This matching is the basis for high extraction accuracy.

3．Principle

The pixel-oriented extraction method can improve work efficiency to a certain extent because the background information is removed layer by layer, thereby allowing fast computer processing. This method is simple and quickly segments the ground classes with obvious interpretation features. Moreover, the method provides a completely new process by transforming direct extraction into indirect extraction.

The object-oriented image analysis method essentially differs from the traditional pixel-oriented method, as it operates with the polygonal objects of homogeneous pixels instead of isolated pixels. Hence, this method can fully utilize the high-resolution remote sensing image information, which includes shape, texture, position, and context. It represents a new technical innovation of the traditional remote sensing classification and extraction.

5. Conclusion

This study investigated two rapid extraction methods for earthquake-collapsed building information: pixel-oriented and object-oriented methods. For the pixel-oriented method, a multi-layer regional segmentation idea was proposed. The idea involved separating layer by layer the non-damaged building information as background from the original remote sensing image. For the object-oriented method, a three-layer classification hierarchy was constructed according to different segmentation scales. The eigenfunctions were selected to construct the fuzzy classification rules.

Compared with traditional interpretation methods for earthquake disaster information, the two methods explored in this study can both extract earthquake-collapsed building information quickly, accurately, and efficiently. Through the analysis of the extraction accuracy, visual effect, and principle of the two methods, we proved that the object-oriented method successfully solves the problem of pepper salt noise caused by the spectral diversity of high-resolution remote sensing data and achieves highly scientific, reliable, and precise results. This method adopts multi-scale image segmentation as well as a fuzzy classification system and takes full advantage of attribute information. The object-oriented image analysis method was found to have unparalleled advantages in information extraction and classification based on high-resolution remote sensing.

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