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Review Article

A review of road extraction from remote sensing images

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ABSTRACT

As a significant role for traffic management, city planning, road monitoring, GPS navigation and map updating, the technology of road extraction from a remote sensing (RS) image has been a hot research topic in recent years. In this paper, after analyzing different road features and road models, the road extraction methods were classified into the classification-based methods, knowledge-based methods, mathematical morphology, active contour model, and dynamic programming. Firstly, the road features, road model, existing difficulties and interference factors for road extraction were analyzed. Secondly, the principle of road extraction, the advantages and disadvantages of various methods and research achievements were briefly highlighted. Then, the comparisons of the different road extraction algorithms were performed, including road features, test samples and shortcomings. Finally, the research results in recent years were summarized emphatically. It is obvious that only using one kind of road features is hard to get an excellent extraction effect. Hence, in order to get good results, the road extraction should combine multiple methods according to the real applications. In the future, how to realize the complete road extraction from a RS image is still an essential but challenging and important research topic.

1. Introduction

Since the first American land observation satellite launched in 1972, all kinds of technologies applied to the RS image processing have developed rapidly, including image compression, transmission, classification, fusion and understanding. All of those high resolution RS images such as IKonos, QuickBird, WorldView and GeoEye create a quick and economical way to access the newly acquired geographic information, and lay a very important basis for the further applications of RS technology.

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The applications of the high resolution RS image processing mainly include the following aspects: city remote sensing, basic geographic mapping, environmental monitoring and assessment, precision agriculture, and public information service, etc (Wang et al., 2013). The goal of the RS applications is to extract information and identify interested targets to complete image understanding. The road extraction from a RS image is a challenging but important research topic. Roads are the backbone and essential modes of transportation, providing many different supports for human civilization. The research of road extraction is of great significance for traffic management, city planning, road monitoring, GPS navigation and map updating, etc (Shi et al., 2014).

This paper makes a summary of different road extraction methods from RS images for nearly 30 years. Meanwhile, it also focuses on the new achievements and results in recent years.

The rest of this paper is organized as follows: Section 2 describes road features, road model, the existing difficulties and interference factors of road extraction techniques. Section 3 shows different road extraction methods and the main research results. The conclusions are presented in Section 4.

2. Road features and models

The difficulties of road extraction from RS images lie in that the image characteristics of road features can be affected by the sensor type, spectral and spatial resolution, weather, light variation, and ground characteristic, etc. In practice, a road network is too complex to be modeled using a general structural model. Hence, the analysis of road features and road models is very important. In the following part, these two aspects will be described.

2.1. *Road features*

In general, we have to make an image enhancement so as to extract useful information from a RS image. A road in a RS image appears as elongated geometric features with slowly changed gray values. As described by Vosselman and Knecht (1995), the road features in an image are summarized from four different aspects. Based on their description, the road features in an image can be concluded as follows:

(1) Geometric features

A road has a stripe feature its width does not suddenly vary much and its length is not as short as its width. The ratio between length and width is very large. The road junctions usually can be presented as the signs of "T", "Y", or "+".

(2) Photometric features

Photometric features are also known as radiation features. It means there are two obvious road edge lines, and the edge gradient is larger. Meanwhile, the gray values or colors of roads are relatively consistent and change slowly, but they are very different from those of the neighboring non-road areas such as trees and buildings, etc.

(3) Topological features

Generally, a road has intersections. The road network is not suddenly interrupted.

(4) Functional features

A road has specific functions in the real world. In order to realize those functions, it must have some constraint conditions.

(5) Texture features

Textures in an image have the regional characteristics, which are a kind of visual features to reflect the homogeneity phenomenon in the image. It has nothing to do with the color and intensity information. The essence of texture features is to find the spatial distribution of pixel gray levels in the neighborhood (Wang et al., 2014).

Different road features in an image have different properties for road extraction. Geometric features have the direct relationships with the road shapes. Photometric features are close to the road gray levels or colors. Topological features and functional features are relatively simple but hard to apply in real applications.

In practice, many road extraction methods use multiple road features rather than only one feature. However, due to the influence of illumination, shadow and occlusion, a road in an image does not have all the features mentioned above, which makes it difficult to extract road from a RS image.

2.2. *Road model*

The road model establishment can help us extract road more effectively. Baumgartner et al. (1999) proposed a classical road model according to the form of road in a RS image, which is shown in Fig. 1.

In practice, the RS image quality can be affected by different factors such as the sensor type, spectral and spatial resolution, weather, light variation, and ground characteristic, etc. Hence, the following interference factors must be considered (Herumuti et al., 2013; Shi et al., 2014; Zhang, 2007):

(1) The observed appearance of a road from a RS image has large variations (spectral reflectance, objects shadow, occlusion, and contrast), which makes the image segmentation more difficult.
(2) In the bad weather, the vague gray value difference between road and background makes the road edge fuzzy, which leads to a bad segmentation result.
(3) The road width is designed at different levels to meet different requirements. All roads with different widths and lengths intersect together.
(4) Discontinuous phenomenon is easy to appear because of the influence of object shadow, occlusion, especially the influence of tunnel and underground.