Extraction of cross-sea bridges from GF-2 PMS satellite images using mathematical morphology

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Abstract: Cross-sea bridges are typical target of natural sceneries. Extracting cross-sea bridges from remote sensing images appears significant. In this study, for the complexity of ground objects in GF-2 PMS satellite images, we have selected direction-augmented linear structuring elements to be used for extraction of cross-sea bridges. Firstly, pre-processing of original image has been carried out; secondly, calculate NDVI and extract water bodies; thirdly, according to the direction of water bodies, select appropriate direction-augmented linear structuring elements, proceed mathematical morphology operations on the water bodies, and assisted by prior knowledge of the bridge, extract the bridge object; finally, select an experimental area to verify the effectiveness and applicability of the method. Our work shows that the direction-augmented linear structuring elements are effective and efficient for extraction of bridges with different directions in GF-2 PMS satellite images, and the approach in this study is important to expand the application areas of domestic high-resolution remote sensing images.

1. Introduction

Information extraction is the hotspot and difficult point in remote sensing image processing on current. As cross-sea bridge is an important artificial building and transportation hub. Due to this particularity of its location, accurately recognition and precise positioning of the bridge target is beneficial not only for the timely update of geographic information data, but also for the disaster prevention and reduction, and the function as a prior referential knowledge for other objects.
In recent years, many methods of bridge extraction have been proposed using remote sensing images. In summary, the methods can be roughly divided into three categories: the method based on difference image, edge detection, and the method based on road information. These three methods have achieved a certain extent of success in some applications. The method based on different image has problems such as hard control on the times of erosion and dilation, and unicity of structural elements despite the fast operation speed. The method based on edge detection picks up bridge targets only by the feature of parallels, not considering the location relationship between the bridge and the river, leading to more production of false information and the uncertainty of the Hough transform parameters. The method based on road information requires the knowledge known of road information, at the same time road information extraction is a difficult point in remote sensing image understanding, which means this kind of method has some theoretical importance but bigger difficulty in practice.

Considering the complexity and particularity of ground objects in remote sensing images, aiming at the flaws such as geometric form’s unicity, and weak directivity of structuring elements in mathematical morphology, in this paper, direction-augmented linear structuring elements are selected, and be used for extraction of cross-sea bridges with different directions in remote sensing images, to solve problems like incompleteness of extraction in utilizing common structuring elements to extract the same category ground objects with different directions in one remote sensing image.

2. Method
The specific flowchart is shown in figure 1. The main steps are divided into image pre-processing, separation of land and sea, extraction of cross-sea bridges and precision evaluation.

2.1 Image pre-processing
During imaging, due to the influence of atmosphere and flight attitude, the quality of the original image can’t meet the requirement of target recognition. So, the image needs a pretreatment to improve the quality and enhance the accuracy of target recognition.

2.2 Separation of land and sea
Water extraction plays a decisive role in the correct recognition of bridge target. In this paper, the
NDVI is calculated, and a threshold value is selected for extraction of water bodies.

2.3 Extraction of Cross-sea bridges

On the basis of water extraction, according to the directions of the water bodies, pick the corresponding direction-augmented linear structuring elements (as shown in figure 2), respectively, and carry out mathematical morphological operations, to connect the broken water bodies because of the bridges. Then, conduct overlay analysis with the result of water extraction, potential bridge targets can be obtained. After that, based on the prior knowledge of the bridges (rectangle fit, minimal area, etc.), verify the potential bridge targets to wipe out invalid information and obtain initial bridge.

To obtain more accurate bridge targets, post-treatment is necessary on the initial bridge targets. The opening operation has the functions of eliminate tiny objects, can smooth the image, eliminate the tiny objects in highlights (e.g. the burr on the edge and isolated spots), and the closing operation has the effect of filtering on the image, able to fill the small holes and cracks of the image. So, the opening and closing operation are needed for the initial bridge targets to acquire more accurate results.
2.4 Precision evaluation

Precision evaluation is not only the standard for judging the evaluation method and the influence on following applications, but also an important basis for evaluating the method performance, adjusting model parameters, optimizing extraction process. This article verifies the results from two aspects of qualitative and quantitative evaluation. By definition, qualitative evaluation is to judge the extraction results by visual observation with the support of prior knowledge by the observer; quantitative evaluation is to judge the extraction results using statistical parameters. For the bridge targets, the former mainly includes the quantity, location, shape and so on, whereas the latter mainly includes the length, the width and the area.

3. Experiment and analysis

3.1 Data

The GF-2 satellite is a Chinese sun-synchronous, high-resolution satellite. It was launched on 19 August 2014. The GF-2 satellite is equipped with two cameras of 0.8 m panchromatic and 3.2 m multispectral resolution with 23 km width.

As a case study, a part of an multispectral image with the size of 3023×2538 pixels from Zhoushan in China is chosen, which is taken in February, 2016, with the spatial resolution of 3.2 m. Figure 3 shows study area and the original image.

It can be seen that, this remote sensing image includes ground objects like bridges, roads, forest and water bodies. The bridge across the sea and links with the road. Affected by the spatial resolution, lanes interval lines on the road are very clear. Affected by the flow of the water and the layout of the road, the directions of four bridges are not the same. Therefore, the algorithm is required to accurately recognition and precise positioning every bridge.
3.2 Experiment and results
The images are clear and high-quality because of good weather conditions, the water bodies have a sharp contrast with other objects. The NDVI threshold value of water bodies information is 0. The result, shown in figure 4, indicates that the water bodies extracted from the image are complete, and the boundary of which is sharp.
When the water bodies are extracted accurately, the direction-augmented linear structuring elements at four different directions (33.75°, 45.00°, 56.25° and 135.00°) are employed to perform mathematical morphology operations on it to identify the potential bridges. The threshold values of the rectangle degree and the area are 0.50~1.0 and 500~20000 pixels respectively, which are selected to screen out the false bridges and obtain the initial bridges. Finally, the initial bridges are executed in post-processing by opening and closing operation of mathematical morphology to determine the true bridges. The overlap image is generated by result image and original image, as the figure 5 shows. It is obviously observed that the four bridges can be identified exactly. Comparing with the real bridges, the position is accurate and the shape is complete of bridges extraction in our study.
3.3.1 Qualitative evaluation. By comparing the visual interpretation result of the original image and the extraction result, we can get the following conclusion. As to quantity, there are four bridges in the original image, the same as the extracted bridges. As to location, the extracted bridges match with the real ones very well. As to shape, the other three bridges are rectangular as same as the real bridges, expert Xiangjiaomen bridges.

3.3.2 Quantitative evaluation. We calculate the length (in direction of the water body), the width (in direction of the road) and the area of every single bridge. See details listed in table 1.

| Table.1 Quantitative evaluation of bridge targets (the unit is pixel) |
|---------------------------------------------------------------|
|                  | real | extracted | deviation (%) | real | extracted | deviation (%) |
|---------------------------------------------------------------|
| **Xihoumen bridge**                                             |      |           |               |      |           |               |
| length             | 517  | 514       | 0.58          | 229  | 231       | 0.87          |
| width              | 12   | 12        | 0             | 12   | 12        | 0             |
| area               | 9160 | 8112      | 11.44         | 2324 | 2187      | 5.89          |
| **Taoyaomen bridge**                                           |      |           |               |      |           |               |
| length             | 194  | 197       | 1.55          | 49   | 49        | 0             |
| width              | 12   | 12        | 0             | 12   | 12        | 0             |
| area               | 2785 | 1912      | 31.35         | 633  | 541       | 14.53         |

The quantitative evaluation result is shown in table 1. When it comes to length and width, extracted bridges match well with true bridges, the max deviations between the extracted bridges and the true values is 1.55%. For area, because of large content of suspended sediment, the water extraction is not complete, so the extracted bridges is not completely, the maximum error for the Xiangjiaomen bridge is 31.35%. In the real world, a real bridge usually has a part located on the land, but all parts of extracted bridges are over rivers because the extraction process is based on the water extraction.

4. Conclusion and Discussion
For the defects of mathematical morphology that the geometric shapes of common structuring elements are too simple and unidirectional, direction-augmented linear structuring elements with directions are constructed and applied in the extraction of cross-sea bridges in GF-2 PMS satellite images. Our work shows that the direction-augmented linear structuring elements presented in this paper can relatively correctly extract bridges with different directions and basically satisfy the need of actual application.

But, in this study, the bridge extraction is performed on the basis of extracted water bodies, the recognition accuracy and positioning preciseness of bridge depend on the effect of water extraction. So, develop more effective method of water extraction in order to extract water body more accurately, get real width of bridge (in the direction of the road) using more prior referential knowledge, and get the direction-augmented linear structuring elements with direction to extract cross-sea bridges are our future work.

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