Analysis of Urban Spatial Structure based on Index Superposition and Color Distance Calculation: An Example based on the City of Honghu

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Abstract. Superposition of multiple index method is used to construct index-fusion remote sensing images, and color statistical analysis and color distance calculation are carried out for urban areas in the fusion remote sensing images to automatically extract the large-scale construction land. The evaluation of the accuracy of the automatically extracted construction land can be done by using high precision Google Earth images. Center of gravity of the automatically extracted construction land is taken as the measurement index of urban spatial distribution, and the dynamic changes of urban spatial structure are analyzed according to the center of gravity. Experiments show that this method can effectively distinguish construction land from other ground objects, thus realizing the high accuracy extraction of construction land. And the center of gravity of Honghu City shows a development pattern and its possible influencing factors for small cities in central China.

1. Introduction
Urban spatial structure mainly represents the spatial distribution of a city. The study of urban spatial structure has a great significance to the development of the city.

Urban area is a complex of various land types, mainly including the construction land, where the vegetation, water, bare soil and sand are included as well. The extraction and analysis of construction land is an important means to study urban spatial structure. By using the center of gravity of the extracted construction land as the measurement index of urban spatial distribution, the dynamic changes of urban spatial structure can be analyzed, which lays a foundation for the research based on the dynamic changes of urban spatial structure. Through studying the difference of the spectrum between the construction land and other ground objects in Honghu City, this paper adopts the method of multiple index fusion and color distance calculation to carry out the extraction of large-scale urban construction land and using high-resolution Google Earth images to evaluate the accuracy of the automatically extracted construction land. In addition, center of gravity is used to analyze the dynamic changes of the whole and the downtown of Honghu City.

Honghu City is located in central and southern Hubei Province, southeast of Jianghan Plain. There are 102 lakes in Honghu, which is an important wetland nature reserve in China and is known as the kidney of Hubei Province. The proportion of the three industries is similar in Honghu, among which the primary industry is mainly agriculture. The land area of Honghu city is 2,519 square kilometers, accounting for about 1.39% of the total area of the province. Among them, agricultural land (including
cultivated land, garden area, forest and other agricultural land) is 165,813.33 hectares, accounting for 66.49% of the total land area (the same below). The construction land is 16560 hectares, accounting for 6.64% and the unused land is 67000 hectares, accounting for 26.87%. It could be seen that the main type of land use in Honghu is agricultural land. Thus, this makes it more difficult to extract the construction land of Honghu city with high accuracy.

2. Related work
The efficient extraction of construction land from remote sensing images has always been the focus of researchers.

A common way is studying the spectral characteristics of construction land and other land types to construct a new remote sensing index, which could enhance the difference between construction land and other land types in the remote sensing images and help to carry out the automatic extraction of construction land [1]. Although this kind of method can enhance construction land in remote sensing images to some extent, it is difficult to effectively distinguish construction land from bare soil, especially the remote sensing image has a large-scale of bare soil. Kajimoto M et al. [2] propose a method that robustly extracts urban areas from polarimetric synthetic aperture radar (SAR) images. In this method, volume scattering power (PV) and total power (TP) are used to distinguish urban area and mountain from farmland, bare ground and sea surface. Polarization orientation angle (POA) is used to classify mountain and urban area. Xiong Junnan et al. [3] proposed a way to extract construction land through the method of comprehensive analysis of the numerical characteristics between different index values for different land types and choose the optimal threshold for each index. Usually, the optimal threshold is limited by experience. Besides, different sampling methods will also influence the selection of optimal threshold. Enhanced morphological method can also be used to extract the construction land [4]. However, the parameters controlling the length-width ratio and area of the connected area need to be set empirically, and the original images require high spatial and spectral resolution. Kakooei M [7] combine processed Sentinel-1 Urban mask and Sentinel-2 indexes statistics to produce high temporal resolution urban maps, and use a ruleset to estimate the probability of that. Different indexes also used to generate Sentinel-2 indexes statistics in this method.

In this paper, by studying the relationship between crop tillage types and tillage period of Honghu City, different indexes construction (MNDWI I, NDVI II, NDBI III) were carried out for remote sensing images of Honghu City in different periods, and the constructed indexes were fused to generate fusion images. Color statistics in different color channels and color distance calculation were performed on the fused images to automatically extract the large-scale construction land. Experiments show that this method can effectively distinguish construction land from water, vegetation, bare soil and sand, thus realizing the high-precision extraction of target objects.

3. Construction of fusion images
Through the analysis of crop tillage types, crop tillage period and the use state of bare soil, it is found that most of the bare soil in Honghu City is agricultural land, and its base period is mainly concentrated in crop fallow period. In terms of farming types, the main crops in Honghu City can be divided into paddy field and dry land, where the bare soil is mainly dry land. The exposed land area of Honghu City is broader in November and December than in other months, and narrower in June, July and August. The spatial distribution of exposed land area varies in different months.

Combining with this feature, the research data came from the images of Honghu City in June 2013, July 2013, June 2019 and August 2019 of OLI, Landsat 8 satellite*. All data are used to construct MNDWI, NDVI, NDBI indexes respectively. MNDWI image in June 2019 is superimposed with NDBI and NDVI images in August 2019 to form a fusion image, and set MNDWI red channel, NDBI green channel and NDVI blue channel to display the fusion image (see Figure 1).
Figure 1. Different indexes RGB color space fusion images of Honghu City. (a)2013; (b)2019.

4. Color distance calculation

4.1. Comparison of feature types in different color space

Different methods could be used to calculate the distance of different color. A commonly used color distance calculation is Euclidean distance based on HSV color space or RGB color space. In this paper, we transformed the fused images from RGB color space to HSV color space, and analyzed the differences between construction land and other ground objects in HSV color space. In the HSV color space, the color categories of ground objects are significantly increased. And The construction land cannot be clearly distinguished because the color of construction land is similar to that of sand. (see Figure 2).

Figure 2. Different indexes HSV color space fusion images of Honghu City. (c)2013; (d)2019.

Finally, Euclidean distance calculation (1) of RGB color space is selected to extract the construction land in this paper.

\[
\text{Dist}(X_i, Y_i) = \sqrt{((X - Y)^2)}
\] (1)

4.2. Euclidean distance calculation based on RGB color space

In this stage, the construction land feature points of the index fusion images of Honghu City in 2013 and 2019 were extracted, and the RGB component values of each feature point were analyzed from the index fusion images. The statistical results are shown in Table 1, in which the RBG component values are the average value of the statistical feature points.

| component value | 2013year   | 2019year   |
|-----------------|------------|------------|
| R               | 0.3317     | 0.4220     |
| G               | 0.6919     | 0.4842     |
| B               | 0.4353     | 0.4369     |
The gray values of each pixel of the fused image and the gray values of the pixel in Table 1 were calculated by Euclidean distance to obtain the color distance calculated images (see Figure 3).

**Figure 3.** Image of Color distance calculation results of Honghu City. (e) 2013; (f) 2019.

### 5. Construction land extraction and precision evaluation

With an analysis given to the pixel gray value of the color distance images of Honghu City in 2013 and 2019, an optimal threshold value could be selected to extract construction land. In this paper, through the comparative analysis of different thresholds, 0.25 was finally selected as the best threshold to extract construction land. The contour of construction land extracted under this threshold is relatively complete, and there are only minor mistaken extractions and omissions. The extracted results are generated by threshold binarization (see Figure 4).

**Figure 4.** Threshold binarization extraction results of urban building contour of Honghu City. (g) 2013; (h) 2019.

By comparing Google Earth high-resolution remote sensing images with the construction land contour images extracted in this paper, the results show that the construction land contour images extracted in this paper are of high precision. Except for a small amount of sand mistakenly extracted from the remote sensing image of Honghu City in 2019, construction land contour in other areas is extracted with high precision.

### 6. Dynamic analysis of urban spatial structure

#### 6.1. Dynamic analysis of the whole urban spatial structure of Honghu City

In order to better study the dynamic changes of the overall spatial structure of Honghu City, all color distance images were imported into ARCGIS to calculate its mean center and median center as different kinds of center of gravity of Honghu City. Considering the influence of extracted sand on the dynamic
analysis of urban spatial structure, it is necessary to artificially eliminate the mistakenly extracted sand soil before calculating the mean center and median center. The calculation results are shown in figure 5.

It can be seen from the figure 5 that the change direction of the whole urban space in Honghu City in the past five years mainly moved to the southeast. While this tendency was represented in more detail by the median center. The difference of development speed between different regions in Honghu City was found, with the development rate of the cities along the Yangtze River in the east of Honghu was higher than that of the inland areas in the west. The main factor of this trend is the natural condition. Compared with the inland areas of Honghu City, the riverside areas had a better water conservancy conditions, which means they had better water resources and water transport conditions to promote the development of the cities. Besides, by comparing the time-span images, it could be found that the development speed of the downtown was faster than that of other areas, which leading the overall center of gravity would move to the southeast direction. This also means that the development of Honghu City in recent five years was mainly concentrated in the city center.

![Figure 5. The center of gravity of Honghu City. (a) Mean centre of Honghu City in 2013 and 2019; (b) Median centre of Honghu City in 2013 and 2019.](image)

6.2. Dynamic analysis of downtown area spatial structure of Honghu City

In this paper, median center and mean center are uses to study the urban spatial structure of the downtown area of Honghu City as well. It is found that the downtown area showed an expansion trend in recent five years, and the overall expansion trend extended along the southwest - northeast trend. (see Figure 6). It can be also seen from the median center and mean center of downtown that the dominant expanded direction was northeastward.

Through the analysis of the traffic, natural condition, economy and development strategy in the downtown area, it could be found that the shift trend of center of gravity was influenced by these factors simultaneously. The two main highways which through the downtown area were extended along the southwest - northeast direction. It could be concluded that the downtown area of Honghu City is more likely to develop along the traffic arteries to some extent. In natural condition, the downtown area was located between the Yangtze River and Honghu Lake, so the extend of downtown from southeast to northwest was restricted by the topographic influence. In economy and development strategy, Honghu borders on Hannan district in the north. Hannan district is belong to Wuhan, which is the capital city of Hubei province, as well as one of the important cities in central China for economic development. Therefore, developing alongside the southwest - northeast direction is more conducive to the economic interaction between the Honghu and Wuhan.
Figure 6. The center of gravity of downtown of Honghu City. (a) Mean center of downtown in 2013 and 2019; (b) Median center of downtown in 2013 and 2019.

7. Conclusion

There are many ways to extract construction land of urban area in the remote sensing images.

In this paper, the method of superposition of remote sensing index and calculation of color distance are carried out to extract the information of construction land. In this method, the selection of the original images is quite important, it does not require high resolution of the original images, but it is necessary to fully analyze the similarity and difference characteristics of ground objects and construction land in the study area, among which the most important ones are the difference characteristics of bare soil, sand and construction land. In addition, there are many dynamic analysis methods for urban space, the limitations of this paper are that only the center of gravity of construction land is used to study the dynamic change of urban spatial structure in Honghu, more methods can be applied here.

Considering that the city's short-term dynamic changes are not obvious, this paper selects 5 years as a change scale for analysis.

I MNDWI index is used to distinguish construction land from paddy fields and water
II NDVI index is used to distinguish construction land from vegetation
III NDBI index is used to enhance construction land information in remote sensing images

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