GEOSCENE MODELING AND ANALYSIS FOR URBAN FUNCTIONAL ZONES

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ABSTRACT:

Urban functional zones are basic units for human socio-economic activities in cities. Urban functional zones play an important role in a wide range of urban studies, as they are fundamental to urban planning and management, urban resource allocation, as well as urban sustainable development evaluation. However, existing studies of urban functional zone modeling and mapping mainly employ state-of-the-art image segmentation and deep learning classification methods in computer science field to delineate and recognize urban functional zones, but ignore their heterogeneity, integration, multi-scale, and locality characteristics, so that the accuracy of urban functional zone modeling, mapping, and analysis is limited and interpretable, thus cannot comprehensively meet the requirements of downstream applications. This study, however, proposes a geoscene modeling and analysis framework for extracting urban functional zones, which first delineates urban functional zones by multiscale geoscene segmentation, then characterizes them by hierarchical semantic cognition, and finally recognizes their functional categories by linear Dirichlet mixture model. Although this paper does not present the detailed implementations of the geoscene modeling of urban functional zones, it illustrates the importance and the generally strategy of geoscene modeling in urban functional zone mapping and analysis. Additionally, urban functional zone mapping results of Baoshan District, Shanghai, in 2015 and 2020 are presented to verify the effectiveness of the proposed geoscene modeling strategy.

1. INTRODUCTION

With the acceleration of global urbanization, the number and the volumes of cities have gradually increased (Dubrova *et al.*, 2015). According to the strategic policy of sustainable development in cities suggested by Chinese government, it will be highly recommended to timely and automatically acquire urban-functional-zone maps for assisting urban planning (Tyler and Ward, 2011). Existing studies usually use planning maps to represent urban-functional-zoning information, but they can only represent the expected goals of functional-zone construction in a certain time interval, failing to reflect the real status of urban functional zoning at the current time point. In addition, planning maps embrace city blocks as the basic units, ignoring the heterogeneity of functional types within blocks, and thus are unable to investigate functional zones at a finer scale. Therefore, only using planning maps cannot update and calibrate urban planning in real time, and cannot meet the requirements of urban sustainable development. Accordingly, the study aims to resolve the problem of automatic urban-functional-zone mapping which needs to accurately extract the basic units, spatial patterns, and semantic categories of functional zones. With the development of remote sensing data and analysis techniques, functional-zone mapping based on high resolution remote sensing image has become a feasible solution (Stewart and Oke, 2012). However, three geographic characteristics of urban functional zones should be considered while modeling and analyzing functional zones, i.e., integration, spatial heterogeneity, and scale uncertainty (Luus *et al.*, 2012; Taubenböck *et al.*, 2013).

For integration, functional zones are composed of diverse land covers which are aggregated following a certain spatial pattern and form a certain built environment, which is so-called integration. For spatial heterogeneity, a city usually consists of different functional zones, such as commercial, residential, and industrial zones, and these zones are spatially heterogeneous and cross-distributed in a city. Additionally, these zones can be composed of diverse land covers with variant features, caused by different socio-economic activities; thus, functional zones are highly heterogeneous. For scale uncertainty, using different scales can result in different analysis results of functional zones and draw different conclusions (Feng *et al.*, 2019; Zhang *et al.*, 2020). Essentially, urban functions are coupled with land-cover structures at various scales, and thus functional-zoning analysis strongly relies on scales and can be influenced by scale uncertainty. Considering these three issues, this study proposes a novel concept of geoscene, and also provides the methodology for analyzing geoscenes, dedicated to extraction, expression, and classification of urban functional zones with high-resolution remote sensing images. The geoscene essentially refers to a region that contains relatively homogeneous spatial structures of multiple geographies. The research work in the study includes the following three aspects (Fig. 1). It first delineates urban functional zones by multiscale geoscene segmentation, then characterizes them by hierarchical semantic cognition, and finally recognizes their functional categories by linear Dirichlet mixture model.

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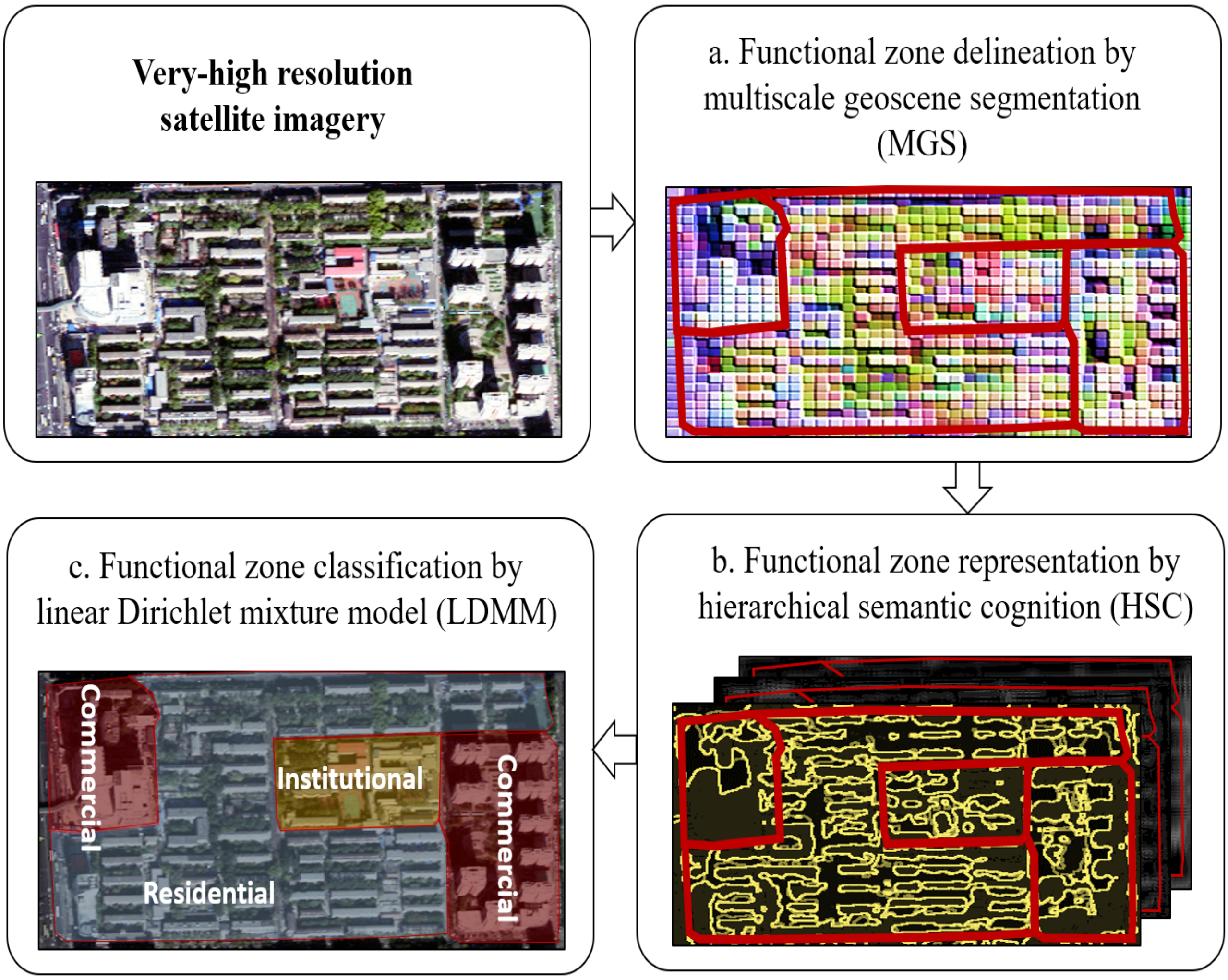

Figure 1. A framework of geoscene modeling and analysis for urban functional zones

2. FUNCTIONAL-ZONE DELINEATION BY MULTISCALE GEOSCENE SEGMENTATION

The heterogeneity of functional zones significantly influences functional-zone extraction (Nowak and Greenfield, 2012; Rojas *et al.*, 2013; Van de Voorde *et al.*, 2011; Taubenböck *et al.*, *2012*). Aiming at resolving this issue and accurately delineating urban functional zones with remote sensing images, this study considers a multiscale geoscene segmentation method (Zhang and Du, 2015a, Zhang *et al.*, 2018b), which can extract functional zones at different scales to meet the requirements of different-granularity urbanization monitoring. However, the segmentation results of functional zones are susceptible to scale parameters, caused by scale uncertainty of functional zones. Accordingly, a method for learning self-adaptive segmentation scales (Zhang and Du, 2016) is used to extract the local optimum segmentation scales, based on which functional-zone boundaries can be delineated accurately. The geoscene segmentation results of Baoshan District, Shanghai, in 2015 and 2020 are presented in Fig. 2, where each segment represents one urban functional zone.

3. FUNCTIONAL-ZONE REPRESENTATION BY HIERARCHICAL SEMANTIC COGNITION

The previous image features, such as spectrums and textures, are weak in representing functional zones, owing to the heterogeneity of functional zones. Aiming at extracting effective features to represent urban functional zones, this study considers a spatial-semantic feature (Zhang *et al.*, 2018a), which models both spatial and semantic relations between land-cover objects within functional zones. This feature is invariant to affine transformation, and thus it can truly and accurately represent functional zones. Owing to the integrity and heterogeneity of functional zones, one kind of features cannot represent functional zones comprehensively. Accordingly, this study also studies visual and semantic features as well as their combinations, and uses a hierarchical structure to organize the different kinds of features. This hierarchical structure can not only express variant features at different layers, but also model the hierarchical correlations among features, which contributes to functional-zone representations (Zhang, Du, & Wang, 2017).

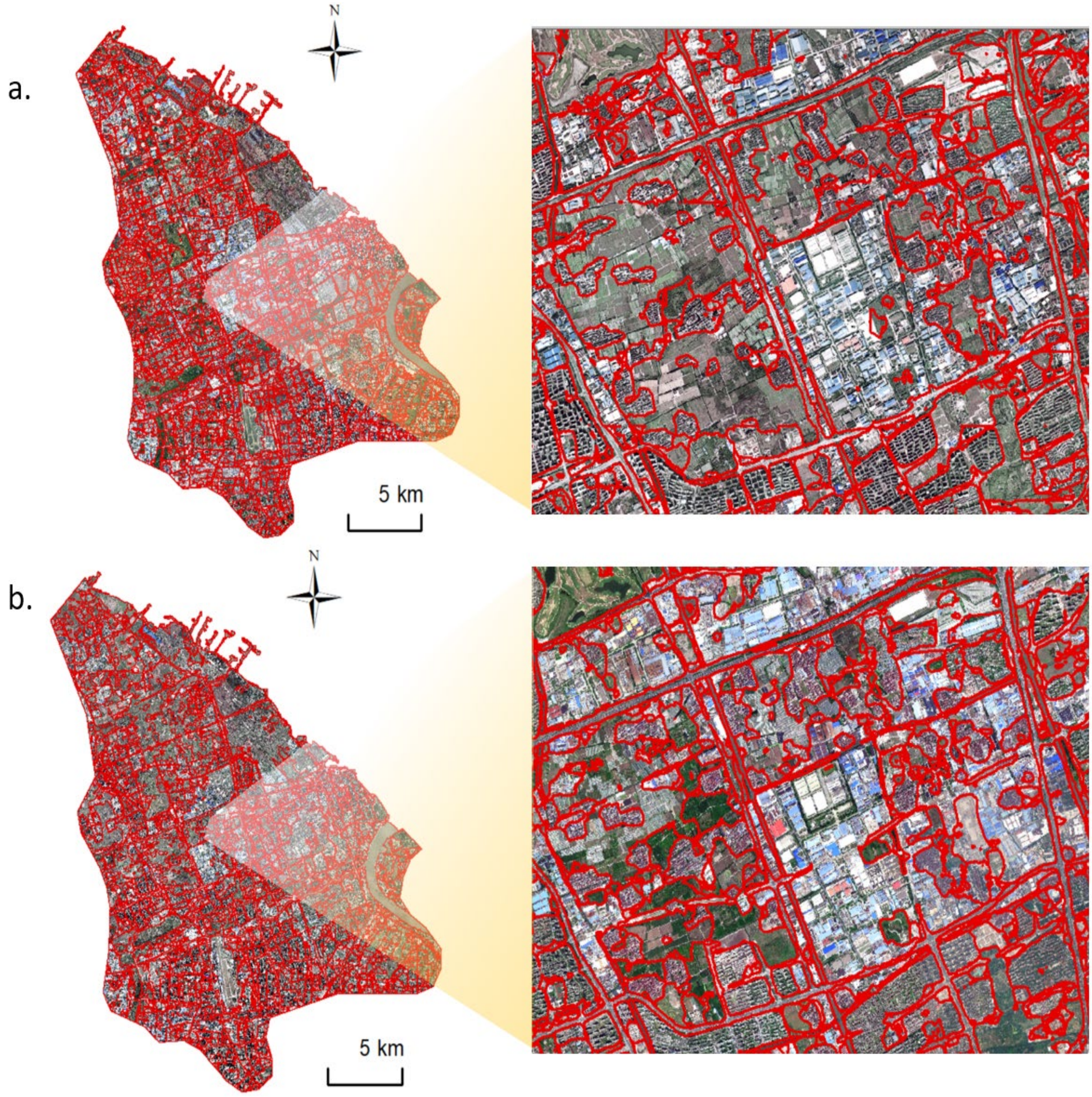

Figure 2. Geoscene segmentation results of Baoshan District, Shanghai, in (a) 2015 and (b) 2020

4. FUNCTIONAL-ZONE CLASSIFICATION BY LINEAR DIRICHLET MIXTURE MODEL

The three geographic characteristics of functional zones, namely integrity, heterogeneity and scale uncertainty increase the complexity of functional-zone classifications (Geiß *et al.*, 2020). Aiming at accurately classifying urban functional zones, the study presents a novel paradigm of supervised classification of functional zones (Zhang and Du, 2015a; Zhang, Du, and Wang, 2015b). A heuristic learning method oriented from active learning is presented, which can collect representative functional-zone samples for supervised classifications. The heuristic sampling is an iterative sampling strategy, which can collect both semantically pure and confused samples. Additionally, a continuous polynomial distribution model is presented to measure the spatial correlations between functional zones, and further used to optimize the classification results of functional zones. Urban functional zone classification results of Baoshan District in 2015 and 2020 are shown in Fig. 3 and detailed in Fig. 4.

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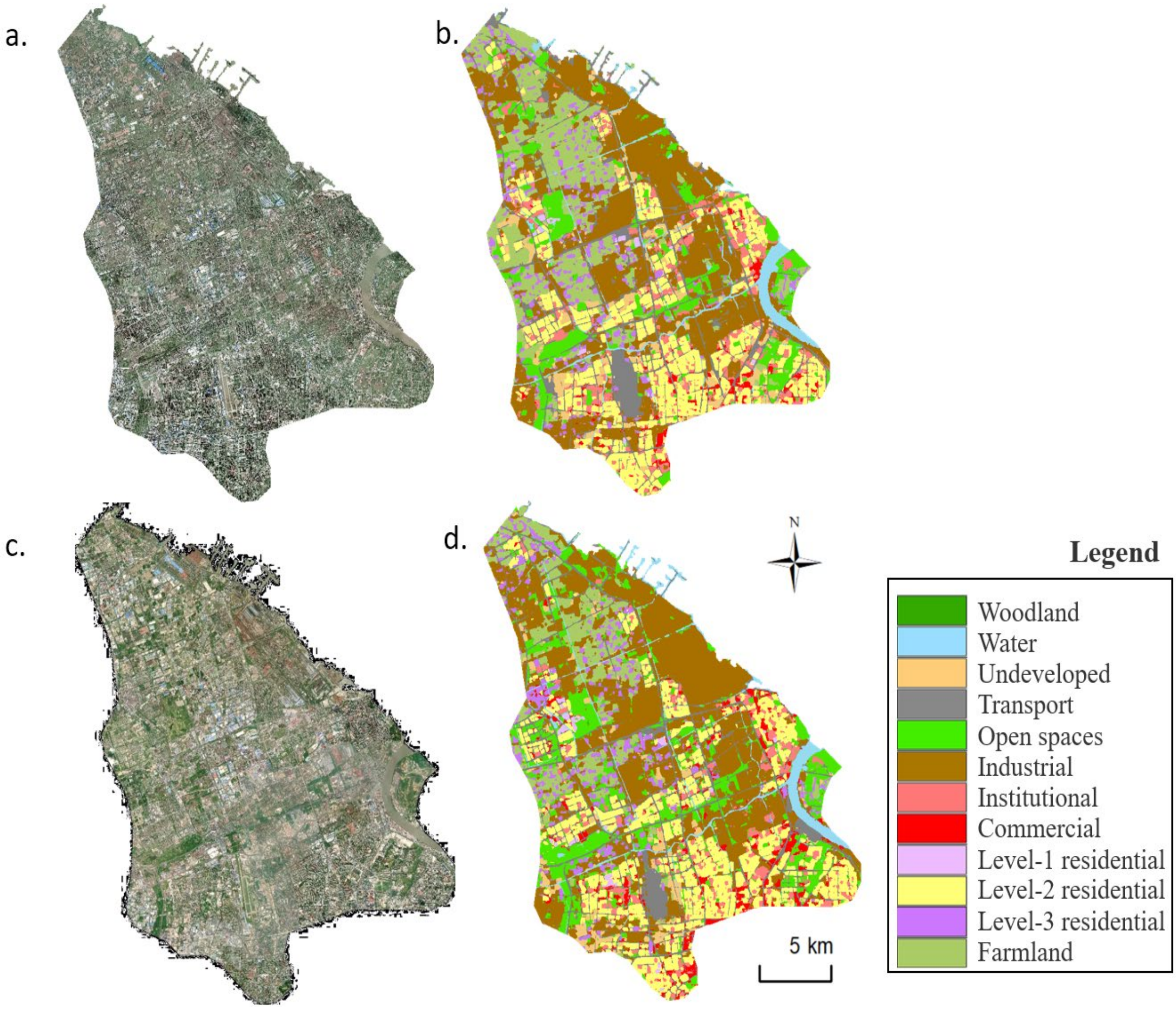

Fig. 3. Functional zone classification results of Baoshan District, Shanghai, in (b) 2015 and (d) 2020

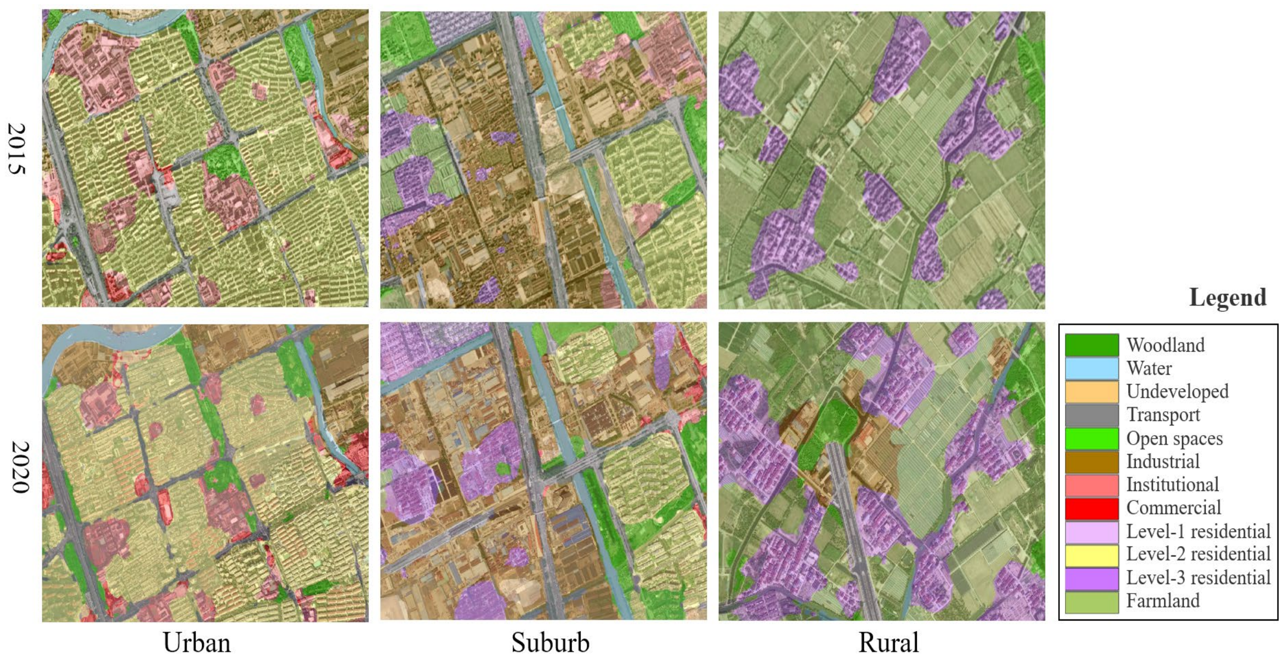

Fig. 4. Functional zone classification results of representative landscapes.

5. DISCUSSION

The study proposes a novel remote sensing image modeling method, i.e., geoscene-based image analysis, and applies it to urban functional zone modeling and analysis, serving for functional-zone mapping, urbanization monitoring, and assisting urban planning. However, there are still some issues in applying geoscene modeling for urban functional zones.

(1) For functional zone delineation or extraction: First, the multiscale geoscene segmentation method is relatively inefficient due to its iterative strategy, so it is not suitable for proposing large scale functional zones, therefore, in the future research, we aim to simplify the iteration method and improve the efficiency of the algorithm. In addition, we also consider employing a big data processing platform to implement large scale functional zone delineation; secondly, how to obtain continuous adaptive scale for functional zone segmentation is a key point of future research.

(2) For functional zone feature representation: First, the error in object classification will affect the measurements of hierarchical semantic features, which in turn will have a negative impact on functional zone classification accuracy, so it is necessary to improve the object classification results in future research work. Second, hierarchical semantic features only measure spatial relationships of objects, but ignore the features of individual objects, such as visual features and abstract features, so that hierarchical semantic features are not comprehensive for urban functional zone representation. In the future, we hope to combine visual features, abstract features and hierarchical semantic features together to express urban functional zones through hierarchical structure, and then further improve the ability for representing functional zones.

(3) For functional zone classification: First, the linear Dirichlet mixture model need large samples, but functional-zone sample learning is not full automation, as it still needs to be done manually for representative samples, so the automation degree of sampling method needs to be further improved. In the future, we hope to introduce sample libraries or historical data or migration data to achieve automatic annotation of the representative samples. Then, the linear Dirichlet mixture model is solely effective for functional zone classification with very-high-resolution satellite image, but will be ineffective for rough-resolution imagery; thus, a more general functional zone classification method needs to be developed.

6. CONCLUSION

In summary, this study proposes a novel theoretical and methodology paradigm of geoscene-based remote sensing image analysis for modeling and analyzing urban functional zones, including functional zone delineation by geoscene segmentation, functional-zone representation by hierarchical semantic cognition, and functional-zone classification by linear Dirichlet mixture model, which is different with classical image analyses, i.e., from image features to land cover categories, and is capable of extracting, expressing, and classifying urban functional zones with high-resolution remote sensing images. The experimental results of functional-zone maps can provide the objective and real-time functional-zoning information for city managers and planners. Therefore, this study plays an important role in urbanization monitoring, urban planning, and management.

In the future, we aim at resolving the issues presented in the Section 5, and further improve the effectiveness and efficiency of geoscene modeling methods.

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