Journal of Transport Geography 45 (2015) 32–47

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

The analysis and delimitation of Central Business District using network kernel density estimation

Wenhao Yu [b], Tinghua Ai [a,b,*], Shiwei Shao [b]

[a] Key Laboratory of Urban Land Resources Monitoring and Simulation, Ministry of Land and Resources, West Hongli Road 8007, Shenzhen, China
[b] School of Resource and Environment Sciences, Wuhan University, 129 LuoYu Road, Wuhan, China

ARTICLE INFO

Article history:
Received 8 September 2014
Revised 15 April 2015
Accepted 23 April 2015

Keywords:
Central Business District
Kernel density estimation
Point of Interest
Network analysis

ABSTRACT

Central Business District (CBD) is the core area of urban planning and decision management. The cartographic definition and representation of CBD is of great significance in studying the urban development and its functions. In order to facilitate these processes, the Kernel Density Estimation (KDE) is a very efficient tool as it considers the decay impact of services and allows the enrichment of the information from a very simple input scatter plot to a smooth output density surface. However, most existing methods of density analysis consider geographic events in a homogeneous and isotropic space under Euclidean space representation. Considering the case that the physical movement in the urban environment is usually constrained by a street network, we propose a different method for the delimitation of CBD with network configurations. First, starting from the locations of central activities, a concentration index is presented to visualize the functional urban environment by means of a density surface, which is refined with network distances rather than Euclidean ones. Then considering the specialties of network distance computation problem, an efficient way supported by flow extension simulation is proposed. Taking Shenzhen and Guangzhou, two quite developed cities in China as two case studies, we demonstrate the easy implementation and practicability of our method in delineating CBD.

1. Introduction

The fast economic growth and rapid urbanization presents a challenge to the limited urban public resources in China. Specifically they encourage a shift in the concentration of urban functions from the monocentric structure to the polycentric structure, which tends to produce a more complex urban environment (Wang and Li, 2002). According to the *Shenzhen Statistic Yearbook of 2010* of our case-study city, the construction acreage of the well-developed region, the Shenzhen Special Economic Zone increased by 64% from 1990 to 2000 but by only about 8% from 2000 to 2010. The city's outskirts became the main areas of city spreading in last decade. As a developing country with a very large population, the change in central urban landscape and functions is critical for promoting sustainable progress in China, since the Central Business District is considered as the economic and social nerve center of the city (Murphy and Vance, 1954; Alonso, 1964; Haggett, 2000).

Highlighting functional areas within cities, such as the CBD or other areas characterized by different kinds of human activities, is an important issue for urban planning field and has drawn the attention of policymakers and scholars (Comedia, 1991; Wang and Li, 2002; Montello et al., 2003). However, many of them require the people to complete complicated and time consuming surveys, and it has proven to be deficient in the management of these emerging urban spaces, such as Shanghai, Guangzhou and Shenzhen. Alternatively the geographical information system-based (GIS) technique, such as the density analysis, acts as an effective means to support the cartographic definition and representation of CBD in a complex urban environment.

The determination of urban CBD has to consider the distribution of different facilities. So the facility distribution characteristics including distribution hot-spot, density and trends, plays an important role in CBD analysis. Previous researches in urban geography have discussed the availability of density surface in the visualization of the urban functional distribution and acknowledged a well-known density analysis method, namely the kernel density estimator in this field. In the era of geographical big data, the increasing availability of crowd-source data and VGI (volunteered geographic information) data (e.g., OpenStreetMap) makes this

* Corresponding author at: School of Resource and Environment Sciences, Wuhan University, 129 LuoYu Road, Wuhan, China.
E-mail address: tinghuaai@gmail.com (T. Ai).

http://dx.doi.org/10.1016/j.jtrangeo.2015.04.008
0966-6923/

method an attractive approach to detect the main distribution properties from large volume data (Thurstain-Goodwin and Unwin, 2000; Okabe et al., 2006; Borruso and Porceddu, 2009). As an efficient spatial statistics tool in spatial density evaluation, the kernel density estimation is superior to other fundamental methods (e.g., Quadrat analysis) in certain classes of application, because it considers the decay impact of services based on the Tobler's *First Law of Geography* (Tobler, 1979; Silverman, 1986; Bailey and Gatrell, 1995). However the application of KDE needs to concern the effect of density distribution under different spaces, especially to consider the distance meaning. Note that most KDE methods assume that the real world is abstracted as an infinitely homogeneous and isotropic space, and use a certain type of kernel estimator with the distance measured by the Euclidean ones. Miller (1994) pointed out that this is probably ill-suited, since many human activities are constrained only to the network portion of the planar space, the so-called network space. Yamada and Thill (2004, 2007) conclude that the planar method tends to overestimate clustering tendency of network phenomenon. It is the network distance rather than Euclidean distance that impacts on the analyses related to social and economic phenomena in urban space (Lu and Chen, 2007; Steenberghen et al., 2010; Okabe and Sugihara, 2012).

Aiming at the question above, this paper provides an applicable approach within network space to facilitate the recognition and delineation of CBD using statistical aggregation of socio-economic point data. Its main contribution lies in the refining of the density surfaces that is restricted by transportation network. Namely, the proposed method uses the new network KDE (KDE based on network distance) instead of a traditional planar KDE (KDE based on Euclidean distance) to transform activity data from point 'object' into continuous surfaces of spatial densities. The estimated density can be considered as an indicator of 'Urban Centredness Index', which supports to delineate CBD by the derivation of key isoline model. As secondary objective, the paper also investigates an efficient network KDE algorithm supported by the stream flowing simulation. The basic idea is that supposes the stream flowing along certain linear channels until arriving at the boundary of 'sphere of influence' or at the end of route. In such process, the network is firstly tessellated into a set of 1-D quadrats to aggregate density value of point activities. Then the assumed streams would spread from each focused quadrat to neighbor quadrats based on the network topology. The quadrats which streams go through can be weighted according to the number of steps to them. Compared to the previous algorithms (Xie and Yan, 2008; Okabe et al., 2009), the proposed method avoids lots of repeat computation in searching shortest path in a graph, and also has the advantages of simple operation and easy calculation. By conducting a kriging interpolation on the resultant 1-D quadrat dataset with density attribute, it is possible to produce a 2-D centredness surface enabling the possibility of generating index isolines.

The remainder of the paper is organized as follows. Section 2 discusses the related development of CBD analysis. Section 3 presents the extension of centredness surface computed from the Euclidean space to the network space and proposes a novel algorithm to implement network KDE based on the stream flowing idea. In Section 4, study areas and experiments in Shenzhen and Guangzhou city are presented. Section 5 discusses the experiment results. Section 6 concludes with future works.

2. Related work

According to the survey of Central Business District from Yan et al. (2000), the literature in the urban study field has suggested that CBD is a common phenomenon that can significantly control the urban renewal and evolution. From a theoretical perspective, this important phenomenon involves the aggregation process of human activities in urban space; then how to quantitatively evaluate such process using spatial statistical techniques becomes the key to CBD delimitation.

2.1. Theoretical aspect: CBD delineation in urban study

The CBD, described as the 'heart of the city' by Murphy and Vance (1954), is located in the central part of a city, together with particular central activities, such as banks, offices, hotels, cinemas and theatres. Because of CBD's central role in urban development and human life, there are many empirical evaluations and observations in urban studies trying to narrow the center of business and identify it (Thurstain-Goodwin and Unwin, 2000; Borruso and Porceddu, 2009; Hollenstein and Purves, 2010). These works generally implement both qualitative and quantitative indexes, with the former being mainly based on individual choices and the latter mainly used in quantitative and distributive analysis.

Classical study in urban geography defines the CBD by mapping land zones that contained the highest concentration of central activities and high land values. Several similar approaches are recently presented with computing indices of central business activity (Thurstain-Goodwin and Unwin, 2000; Borruso and Porceddu, 2009). They are specifically focused on the development of point pattern analysis, starting from data concerning social-economic activities georeferenced at address-point level. Specialized techniques using statistical methods are adopted to attribute the concentration of activities to area units as urban districts and to derive their density. In such sense the core of the city is highlighted in terms of dominance of the economic activities located there. In the era of big geo-data, the crowding-source data and the uploaded VGI data make the urban facility POI (Point of Interest) easily be collected, and also facilitate the urban spatial analysis, such as CBD detection (Hollenstein and Purves, 2010; Elwood et al., 2012; Sun et al., 2013).

Despite the need of new information on CBD, few studies in China have looked at this issue of studying urban development and its functions with spatial statistic methods. As one of the most classic studies in China, Yan et al. (2000) pays attention to the delimitation of CBDs in Guangzhou, a city of South China, in terms of documents, statistical data and on-the-spot investigation. The result reveals that the traditional CBD is dominated by retail activities but the new developing CBDs by professional, finance and insurance, and information consultation. For many cities in China, 'old' urban functions have changed and transformed since the 1980', when the policy of reform and opening to the outside world is implemented (Wang and Li, 2002; Jia et al., 2008). Especially as China's first special economic zone, Shenzhen practices market economy earlier and gains more experience characterized by new urban development mechanism. The city administrative department reports that the location of Business District in Shenzhen is transforming from a single central location to more decentralized ones (UPLRCSM, 2010). In order to analyze an urban environment like Shenzhen or Guangzhou that is constantly changing, we propose a method for automatic delineation of CBD through point pattern analysis of central activities.

2.2. Technological aspect: density estimation supported CBD analysis

This paper explores the vaguely defined phenomena of CBD using officially collected activities data, which is reduced to a simple point in GIS environment. Such type of point dataset contains inherent spatial information for locating places as well as statistical data about other social-economic attributes. After the density of points is computed for area units through density estimation,