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A fast approach for large-scale Sky View Factor estimation using street view images

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ABSTRACT

Sky View Factor (SVF) is one of the most useful urban spatial indicators for radiation and thermal environmental assessment. Estimating SVF with circular fish-eye photos is straightforward and convenient and can account for obstruction of vegetation and other urban infrastructures. But for a large area with many points of interest, processing fish-eye photos is labor intensive. This paper presents a workflow of estimating SVF with large amounts of street view images obtained at sampling points along city road network at the height of about 2 m. To automatically estimate SVF with street view images, a batch processing sky region detection and SVF calculation tool was developed with the Python programming language and OpenCV. The tool can deal with various outdoor weather conditions, and the performance of sky region segmentation and SVF calculation was validated with photos taken with a fish-eye lens. The method shows reliable estimations and preferable speed, with about 1.5 s for a 1000 × 500 px image and 0.08 s for a 200 × 100 px image. The proposed workflow was further applied to estimate the SVF distributions in the downtown centers of four densely populated Chinese cities.

1. Introduction

Urban morphology has a significant influence on the micro-climate of cities, and numerous studies have attempted to reveal the relationship between urban morphology and the outdoor thermal condition. Height to width ratio (H/W) and Sky View Factor (SVF) are among the most discussed urban morphological parameters [1–13]. Sky View Factor (SVF) refers to the ratio of the radiation received by a planar surface to the radiation emitted by the entire hemispheric environment [14,15]. SVF is typically represented by a dimensionless value between 0 and 1, where 0 indicates the sky is completely obstructed by obstacles and 1 indicates there are no obstructions at all [16]. SVF is a widely used parameter to study Urban Heat Island (UHI) effect [17], urban energy balance [18,19], and urban surface temperature [12,20], and controlling SVF can prevent high temperatures in urban street canyons [21]. Oke [22] suggested a negative linear correlation between the maximum heat island intensity and SVF. Unger [23] reported a strong negative relationship between areal averages of SVF and UHI through mobile measurement within a large sample area. Svensson et al. [10] also reported a fairly strong relationship between nighttime street-level air temperature and SVF.

In outdoor thermal comfort studies, SVF is found to be closely related to physiologically equivalent temperature (PET) [6] and mean radiant temperature (MRT) [24,25]. Lin et al. [6] performed a 10-year PET prediction for a hot summer mild winter climate and found high SVF locations are uncomfortable in summer. Among all their studied sites, a SVF of 0.129 has the longest annual thermal comfort period. Holst and Mayer [25] reported a linear relationship between the MRT and SVF in street canyons. Because these thermal parameters also significantly affect the visiting frequency of public spaces [5,26], identifying SVF distribution pattern would be valuable for urban planning and renovation. However, in spite of the abundant studies concerning SVF, previous studies have revealed the need for investigations into a larger number of survey sites or the entire city to obtain the effect of SVF [27].

SVF can be estimated with 3D city model-based methods [28,29], GPS method [30–32], or the fish-eye photo-based methods [16]. Urban 3D model-based methods can estimate continuous SVF distribution in a large area with a short calculating time. A few tools have been developed for this purpose, either standalone tools or GIS software plugins. For example, plugins in ArcView have been developed for estimating SVF using vector-based digital maps that contains building shape information [23,33]. The SkyHelios tool developed by Matzarakis et al. [34,35] can also generate continuous SVF map using Digital Surface Models (DSMs). Furthermore, a few multi-functional urban climatic software packages are able to perform SVF calculations. The SOLWEIG (SOlar and LongWave Environmental Irradiance Geometry model), which is a component of the Urban Multi-scale Environmental Predictor

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(UMEP), an integrated urban environmental assessment tool developed by Grimmond et al. [36] also enables SVF calculation as well as MRT modeling. Some other micro-climatic software also has the SVF calculation function, such as ENVI-met and HURES [37], and most of them are based on 3D vectored processing. A common limitation of the above methods is that vegetation and obstacles other than buildings are rarely included in the available 3D database. However, in real urban environment, other intra-urban obstacles especially the vegetation would also affect SVF estimation [38]. This limitation can be overcome by highly detailed 3D databases. For example, a recently developed SVF calculation tool named SVFEngine [39] enables accurate estimation of SVF using highly detailed 3D urban model obtained with oblique airborne photogrammetry. Although the result can accurately reveal the current urban canopy status with even vegetation into consideration, the required data size could reach several gigabytes for the city scale. Overall, although 3D city model-based methods are fairly efficient once the 3D obstacle database is available, these data sources are not widely available.

Another kind of method, namely the GPS method, estimates SVF through multiple variable regression or Artificial Neural Network (ANN) regression that relate SVF to on-site satellite visibility and signal strength data [30–32]. This method enables real time estimation and works fairly well in urban areas (r = 0.65–0.67), while in rural areas the performance decreases (r = 0.46–0.51), which might be due to the effect of trees.

A number of studies estimate SVF using fish-eye photos [16,40], which can be obtained by taking photos upwards the zenith with a circular fish-eye lens at the ground level. With circular fish-eye photos, the sky region and the obstructed region can be delineated with image processing software. But the process is usually performed manually, one image at a time. Once the sky segmentation process is finished, there are different ways to calculate SVF with circular fish-eye photos. The Rayman software [41] is a micro-scale model that enables estimating SVF, sunshine duration, shadow and thermal indices. It calculates SVF using either 3D building and plant models or fish-eye photos. For the fish-eye photograph calculation mode, the sky region segmentation can be achieved by free-hand drawing or by RGB threshold-based cropping. However, unsupervised automated batch processing of fish-eye photos is not possible with this software [24]. There are three main obstacles in applying this method to large scale SVF assessment: very time-consuming manual image processing, limited surveying opportunities, and ideal overcast sky conditions to ensure sky identification accuracy [28]. SKYVIEW [42] is an application developed for SVF-targeted automated image processing, but the limitation is that the process needs redefining parameters manually and the performance largely relies on perfect overcast weather condition.

Recently, with the development of big data applications, it is realized that street view photos have great potential in urban environmental studies, since the street view images can cover most of the urban areas in the world and provides unprecedented survey opportunity. Street view images, especially Google Street View images are more and more frequently used for scientific purposes. The study by Carrasco-Hernandez et al. [43] is the first that used Google Street View photos for SVF and solar radiation estimation. Liang et al. [44] carried out a pilot study on large-scale SVF estimation using Google Street View and an open source CNN tool named SegNet [45], which aims at identifying different kinds of components in outdoor and indoor images. Another machine learning technique Support Vector Machine (SVM) is reported to be used in street view photo-based street visual enclosure estimation [46]. These studies demonstrate the possibility of unsupervised automated large-scale SVF estimation, and the processing time for a city-scale estimation could be just a few hours if a GPU calculation platform is available. However, the open source CNN tool still took tens of hours for a city-scale estimation on a common CPU platform. It is beneficial to reduce the required time and this should be possible since the recognitions with SegNet are performed for many types of outdoor components while only the sky is needed.

In this paper, we present an efficient workflow for estimating SVF at a large scale using street view photographs. Static panorama images for a large number of sampling points based on road net database can be accessed through API requests. Then an automatic batch processing sky region detection and SVF calculation tool is developed with the Python programming language. The tool can deal with various outdoor weather conditions, and the performance of sky region segmentation and SVF calculation was validated with photos taken with a Nikon FC-E9 fish-eye lens. The method shows reliable estimations and preferable speed. The proposed workflow was further applied to estimate the SVF distributions in the downtown centers of four densely populated Chinese cities within different climate zones.

2. Methodology

2.1. Street view map acquisition

In recent years, Google Street Map is more and more frequently used for scientific purposes [44,46,47]. It covers many cities around the world, but some regions such as China are not covered. However, there are a few alternative map providers, such as Baidu [48] and Tencent [49]. Static panorama images can be accessed via APIs given the field of view (FOV), heading, pitch, image size, longitude and latitude location or panorama ID, etc. More information on keys and values for street view image acquisition can be found through the Baidu website [48]. Baidu provides static panorama images with a maximum FOV of 360° in the horizontal direction and an FOV of 180° in the vertical direction. Fig. 1 shows the example of Baidu Street Map coverage for Shanghai, China (in the light blue mask), and a sample street view image with the size of 600 × 300 pixels. The retrieved panorama images can be directly used for the sky region detection process described in the following section. However, for providers with a maximum FOV of less than 360°, a panorama stitching process with a set of rectilinear street

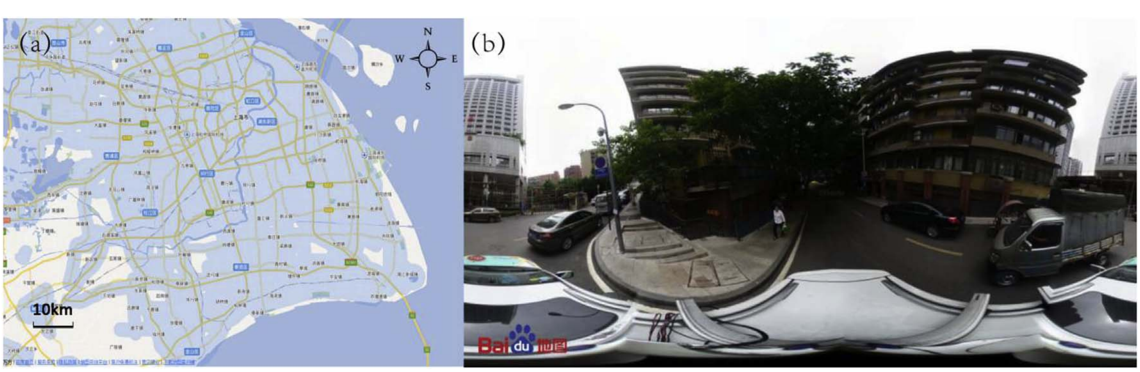

Fig. 1. (a) Coverage of panorama image in Baidu Street View, Shanghai, China; (b) an example of the retrieved panorama (fov = 360 × 180) [48].