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Building population mapping with aerial imagery and GIS data

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ABSTRACT

Geospatial distribution of population at a scale of individual buildings is needed for analysis of people's interaction with their local socio-economic and physical environments. High resolution aerial images are capable of capturing urban complexities and considered as a potential source for mapping urban features at this fine scale. This paper studies population mapping for individual buildings by using aerial imagery and other geographic data. Building footprints and heights are first determined from aerial images, digital terrain and surface models. City zoning maps allow the classification of the buildings as residential and non-residential. The use of additional ancillary geographic data further filters residential utility buildings out of the residential area and identifies houses and apartments. In the final step, census block population, which is publicly available from the U.S. Census, is disaggregated and mapped to individual residential buildings. This paper proposes a modified building population mapping model that takes into account the effects of different types of residential buildings. Detailed steps are described that lead to the identification of residential buildings from imagery and other GIS data layers. Estimated building populations are evaluated per census block with reference to the known census records. This paper presents and evaluates the results of building population mapping in areas of West Lafayette, Lafayette, and Wea Township, all in the state of Indiana, USA.

1. Introduction

The census as applied in many countries is an attempt to gather basic information about the characteristics of the population. This is usually carried out at an interval of 5–10 years with the purpose of obtaining information on demographic, social, economic and housing characteristics and their variation over small areas (Martin, 2000, 2006; Boyle and Dorling, 2004). Apart from the great value of this important effort, one major aspect of population census is its spatial content.

Considering this spatial aspect, geographic aggregation is the most common way of releasing population and socioeconomic datasets. The census population, for instance, is usually publicly available in various geographic reporting zones depending on the policies applied by the country performing the census (Martin, 1996). Spatial analyses on these data may be performed for different purposes and by implementing methods with different assumptions and understanding. Thus, the specific areal unit in which the data are reported does not necessarily coincide with the nature of the phenomena under investigation. The results of the correlation and regression analysis of spatial data may vary based on the size and configuration of the areal units used for the analysis (Flowerdew et al., 2001). Since the data reporting zones are not unique or fixed, it is possible to represent the same data using different aggregations for a more realistic presentation. This is known as the modifiable areal unit problem (MAUP) (Openshaw and Taylor, 1981). Indeed, representation of population in spatial units different from the census zoning may be essential for a better performance of various spatial applications. Some of these applications include criminal investigation, public health, natural hazards risk, environmental risk and accessibility analysis, facilities and retail planning, land use planning, resource allocation, emergency planning, and spatial interaction modeling (Chen, 2002; Langford, 2006; Mennis, 2009).

Representing data in different areal units requires interpolation from the initial source units to target units. One way to achieve this is by dasymetric mapping (Wright, 1936). This is basically a transform of data aggregated to one zone to some other desired zone so as to represent the underlying data distribution more realistically. Dasymetric maps discretize a continuous statistical surface into regions with minimum variation that are divided by boundaries approximating the steepest change (Langford and Unwin, 1994). Such maps aim to have a better depiction of the underlying statistical surface with more homogeneous zones (Eicher

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and Brewer, 2001; Mennis, 2009). In this respect, the information used to define homogeneous boundaries is of importance. In this study, building footprints are used to define the homogeneous zones.

Different approaches to dasymetric mapping have been used in various applications. Land use and land cover, soil type, geological unit or similar ancillary information may be used in dasymetric mapping. Eicher and Brewer (2001) provide detailed information and evaluation on major dasymetric mapping methods. Maantay et al. (2007) also provide a review on methods used for dasymetric mapping. Langford (2006) compares binary and 3-class dasymetric methods. Mennis (2003) describes a dasymetric mapping methodology that incorporates areal weighting and empirical sampling to determine the relation between the ancillary data and population distribution. In a later study by Mennis and Hultgren (2006), a flexible empirical sampling approach is introduced as an "intelligent" dasymetric mapping (IDM) technique that supports several ways to define the relationship between the ancillary data and the underlying statistical surface. At the finer scale, Lwin and Murayama (2009) introduce a GIS approach to the estimation of population for individual buildings.

This study explores population mapping for individual buildings. First, we determine building footprints and heights in residential zones from aerial images, digital terrain model (DTM), digital surface model (DSM) and zoning maps. Building address data, land use maps, and other ancillary information are further jointly used as supplemental data to categorize the extracted buildings as houses and apartments. In the final step, weighted areametric and volumetric models are used to disaggregate the population of census units to individual residential buildings. The rest of the paper is organized as follows. Section 2 introduces the weighted models for population disaggregation. The study areas and test data are described in Section 3. As an implementation of the object-based image classification technique, Section 4 discusses building extraction and evaluates its quality. Section 5 makes a combined use of zoning data, address data, land use maps, and other publicly accessible information to identify residential houses and apartments from the results of the previous section. Properties of different disaggregation models are evaluated in Section 6 by using census population data as the reference. Findings and concluding remarks are summarized in Section 7. Throughout the paper sample data and maps are presented from the cities of West Lafayette, Lafayette, and the Wea Township, in Indiana, USA.

2. Models for population mapping

Population data for a variety of geographic units are publicly available from the U.S. Census Bureau. Of importance for this study are four of these geographic units, from smallest to largest: census blocks, census block groups, census tracts, and townships. Census blocks are the smallest geographic units for which U.S. Census data are tabulated. Streets, roads, railroads, other physical features, legal boundaries, etc. may form the boundaries of census blocks. The next level units are census block groups. A census block group is a combination of several census blocks. Census tracts are geographic entities with more homogenous population characteristics, economic status and living conditions, usually having between 2500 and 8000 residents. The largest geographic unit for this study is the township, which is a minor civil division (MCD) defined as the primary sub-county governmental or administrative unit. (U.S. Bureau of the Census, 2005).

The objective of building population mapping is to distribute the publicly available population of a census unit to individual residential buildings therein. For this purpose, we modify the areametric and volumetric models introduced by Lwin and Murayama (2009) through implementing a weighting scheme

$$P_i = \frac{w_i^S S_i}{\sum_{k=1}^{n} w_k^S S_k} P_c \tag{1}$$

where S_i: taking either A_i for the area or V_i for the volume of residential building i; S_k: taking either A_k for the area or V_k for the volume of residential building k; w_i^S, w_k^S: weighting factors for residential buildings i, and k; P_i: population of residential building i; P_c: population of a census unit; n: total number of buildings within the census unit.

In the above equation, the population of a census unit P_c is available from census. The weighting factor w_i^S represents the population per unit area or volume, which varies with the type of residential buildings. To apply the above model, we need to first find the buildings, recognize the residential ones, and then determine their weighting factors. These issues will be addressed in the following sections.

3. Study area and data

The selected study areas are parts of Lafayette and West Lafayette cities, and the entire Wea township, Indiana, USA. These twin cities are separated by the Wabash River, cover an area of 66.3 km^2, and have a total population of 85,175 based on the 2000 census data. The study area within the city of West Lafayette consists of two census tracts: 51 and 52. The Wea township, approximately 100 km^2 in area, overlaps in part with the city of Lafayette and includes both urban and suburban regions with multi residential, business, industrial and agricultural representative areas. These neighborhoods are relatively similar and comprise many typical residential land covers. There are three different types of major residential zoning observed in the neighborhoods of the study area. These include single family housing, single and two family housing, and single, two and multi-family housing. Single family housing neighborhoods include detached single family houses while single and two family housing neighborhoods include attached twin houses in addition to the single family houses. Neighborhoods of the third zoning class mainly include townhouses and apartment buildings in addition to the single and two-family houses. An overview of the study areas is illustrated in Fig. 1.

As summarized in Table 1, a variety of geographic data over the above study area is used in this work. They include 1 m resolution color infrared (CIR) aerial photos, acquired during March and April of 2005 in leaf off conditions, 1.5 m resolution DTM and DSM derived from the CIR image stereo pairs, current zoning maps, all for the entire study area; building footprints of 2000 and building address point data of 2009 for West Lafayette; land use maps of the Wea township; and 2000 census population data. The CIR images, DTM and DSM were acquired and created as a part of the 2005 IndianaMap Color Orthophotography project coordinated by the Indiana Geographic Information Council (IGIC), and are made publicly available online through a spatial data portal (http://www.indiana.edu/~gisdata/). Though the DSM was generated from the same image sources, it misses a number of buildings present in the imagery. The zoning maps are publicly available from the website of the Tippecanoe County Area Plan Commission (http://www.tippecanoe.in.gov/apc/). They show the boundaries of different zones of current and planned allowable uses, such as single-family residential, multi-family residential, business, industrial and agricultural. Both the building footprints and the address data are obtained from the Tippecanoe County GIS office. Building footprints include the building outlines combined from multiple sources and will be referred to as "county buildings" in the continuing sections. The address data consist of locations