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A Grid-Generation Based Method for Information Fusion

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Abstract: Relative studies on multi-scale information fusion, multi-source information fusion and multi-sensor information fusion are reviewed. On the basis of analyzing problems in existing methods of information fusion, a grid-generation model for simulating population density of China is proposed as a case of multi-source information fusion. By fusing remotely sensed data, meteorological data, soil data and statistical data, spatial distribution of population density in China is successfully simulated, in which grid generation process is described in detail. In addition, the basic idea of a grid-generation model as a case of multi-scale information fusion is discussed. The models for multi-source information fusion and for multi-scale information fusion are two foundational component parts of the grid-generation based method for information fusion.

Keywords: Information fusion, grid generation, multi-scale, multi-source, model

1. INTRODUCTION

1.1 Multi-Scale Information Fusion

The issues on IEA are involved in various scales. At each scale, a set of spatially explicit indicators needs to be identified to characterize the extent, pressures, condition, value and trends of ecosystem types and land use patterns as well as underlying structural features of ecosystems. For any size patch of the earth's surface that we choose to define as an ecosystem, there will be a set of factors external to the ecosystem that influence how it functions and, in turn, there will be flows of material and energy that extended beyond the ecosystem. The larger the scale, the more inclusive it is of these flows of material and energy. However, studies undertaken at larger scales lose the site specificity that policymakers often need. In other words, there is no single scale at which we can obtain a full understanding of ecosystems.

Scale issue is an inherent part of geography and ecology (Withers and Meentemeyer, 1999). From the early 1950s to the early 1970s, many ecologists (Greig-Smith, 1952; Gould, 1966; Hutchinson, 1971) tried to incorporate scale in environmental biology. From the early 1970s to the 1980s, many ecologists focused increasing attention on the problem of spatial scale (Allen and Starr, 1982; Golley, 1989; Gosz and Sharpe, 1989;Wiens, 1989). In 1990s, problem of pattern and scale becomes the central problem in ecology, for unifying population biology and ecosystem science, and marrying basic ecology and applied ecology (Levin, 1992).

The explosion of interest in scale has created many methods for scale. For instance, interpolation brings multiple phenomena measured at different resolution into a common coordinate grid with a single size (Ehleringer and Field, 1993). Multiple-variables scaling method simultaneously examines each variable at different scales (Holling, 1992). Spatially explicit models are simply maps of actual or simulated phenomena to demonstrate scale sensitive issues (Holt et al., 1995). Fractal geometry is used to treat the dependence of various phenomena on scales (Mandelbrot, 1982). Re-sampling techniques are used to frame samples within a hierarchical framework to assess how scale and sequence of assembly affect ecosystem characteristics (Cressie, 1993). Geo-statistical techniques employ knowledge of the spatial covariance to produce a spatial model (Oliver and Webster, 1990). Neural models are developed to test scale effects resulting from changes in grain size and spatial structure (Milne, 1992). Hierarchy theory is employed to address issues of spatial scale, which implies that an ecosystem is composed of interacting components and is itself a component of a larger system (O'Neill et al., 1989). However, all these methods paid less attention to multi-scale information fusion.

1.2 Multi-Source Information Fusion

Since early 1970s, information fusion techniques have been widely applied to military sphere and many information fusion systems have been developed such as TCAC, INCA, PAAS, TOP, DAGR, TATR, AMSUI, TRWDS, ASAS, LENSCE and ENSCS. However, all these information fusion methods are limited within military issues and to information from sensors.

The major two existing relative approaches that are not only limited within multisensor information are observations at fixed positions (or spatial sampling) and retrieval using remotely sensed data. The approach of observations at fixed positions (or spatial sampling) can obtain high precision data at observation points. But observations at fixed positions or spatial sampling are confined within some limited dispersal points and not able to directly calculate relative parameters at regional scale. The parameters at regional scale can be estimated on the basis of the observation data at points by spatial interpolation. However, the direct description of regional properties by using data at points is not able to authentically reflect spatial distribution pattern because of the spatial heterogeneity of relative factors.

In the past, remote sensing applications largely focused on the mapping of environmental conditions or the characterization of ecosystem structure and function at one particular point in time, primarily to establish a baseline condition (Lunetta, 1998). The utilized remotely sensed data and derivative products are in hard copy image or map formats. These products provided a powerful synoptic observation tool to better understand the spatial distribution of ecosystems and to study coarse-scale, but they are unable to carry out information fusion with other types of data. With progress of data processing models and geographical information systems, digital spatial products are widely available, which makes the merging of remotely sensed data with other data types workable. Recent applications of digital remotely sensed data mainly focused on the development of ecosystem baseline conditions and investigation of coarse-scale vegetation dynamics. It is trying to apply remotely sensed data to monitoring dynamics of ecosystem structure and processes.

Processes shaping different ecosystems operate over a hierarchy of temporal and spatial scales. Vegetation composition is hierarchically influenced by climate at regional to continental scales, by landforms at the landscape to regional scales, and by water redistribution and disturbance at local and patch scales. Satellite remote sensing can frequently supply surface information. But remote sensing description is not able to directly obtain process parameters that must be retrieved on the basis of combining remote sensing information with earth surface properties.

2 THE MODEL FOR MULTI-SOURCE INFORMATION FUSION

2.1 Grid Generation Method

In 1960s, grid generation techniques began to be developed (Morrison, 1962; Sidorov, 1966; Ahuja and Coons, 1968). The successful development of numerical grid generation has already formed a separate mathematical discipline. In 1990s, grid generation techniques reached a new stage. Grid generation can be viewed as finding useful parameterizations of maps (Knupp and Steinberg, 1993). The unique aspect of grid generation on general domain is that grid generation is not obliged to have any specified formulation and any foundation may be suitable for the purpose if the grid generated is acceptable (Liseikin, 1999). The most important step is to find an appropriate transformation between computational domain and physical domain for purposes. Grid generation methods based on interpolation have been extensively developed to take advantage of their two main strengths: rapid computation of the grids compared to the partial differential equation methods and direct control over grid point locations. The grid is a foundation, on which continuous quantities are described by discrete functions and on which differential equations are approximated by algebraic relations for discrete values.

2.2 The Grid-Generation Based Model for Simulating Population Density of China

In order to simulate population density of China at every grid point by fusing natural information and economic one, a grid-generation based model is developed in the light of the gravity model (Isard et al, 1960). The grid generation is formulated as a transformation from Euclidean space E^2 to Euclidean space E^3, i.e. from (i,j) to $(i,j,p_{ij}(t))$. If population density $p_{i_0 j_0}(t)$ at grid (i_0,j_0) is known, the simulated population density at any grid (i,j) can be expressed as

$$SPD_{ij}(t)=\frac{p_{i_0 j_0}(t)}{IN_{i_0 j_0}(t)}\cdot IN_{ij}(t) \qquad (1)$$

$$IN_{ij}(t)=G_{ij}(t)\cdot\left(F_{ij}(t)\right)^{a_1}\cdot\sum_{k=1}^{M}\frac{\left(S_k(t)\right)^{a_2}}{\left(d_{ijk}(t)\right)^{a_3}} \qquad (2)$$

where $G_{ij}(t)$ is a function determined by rail transport $ra_{ij}(t)$, road transport $ro_{ij}(t)$, air transport $ai_{ij}(t)$, maritime transport $ma_{ij}(t)$, inland water transport $iw_{ij}(t)$ and telecommunication system $co_{ij}(t)$; $F_{ij}(t)$ is $\sin\left(\frac{NPP_{ij}(t)+3920}{9290}\cdot\pi\right)$ at grid (i,j) if the grid is located in rural area or the urban size if the grid is located in a city; $NPP_{ij}(t)$ is net primary productivity at grid (i,j); $S_k(t)$ is area of the kth city; M is the total number of cities; $d_{ijk}(t)$ is the distance from grid (i,j) to the core grid of the kth city; t is time variable; $a_l(t)$

($l = 1,2,3$) are empirical parameters.

2.3 Grid Generation Process and Results

For lack of data, maritime transport $ma(t)$, inland water transport $iw(t)$ and telecommunication system $co(t)$ are not calculated. When *t* represents the year of 2000, $p_{i_0 j_0}$ takes value of average population density of Beijing in 2000, simulated population density (SPD) of China in 2000 is formulated as,

$$SPD_{ij} = 4.2 \cdot (1 + ra_{ij})^{0.15} \cdot (1 + ro_{ij})^{0.5} \cdot F_{ij}^{\,0.09} \cdot \sum_{k=1}^{M} \frac{S_k}{d_{ijk}} \qquad (3)$$

The major auxiliary tools of grid generation include the Control of MapObjects and Delphi computer language. Six data layers are involved, which are NPP (net primary productivity), GridRail (railway network), GridRoad (road network), and Chbnd (administrative boundary), Chzh(urban area) (Urban Society and Economy Survey Team of National Bureau of Statistics of People’s Republic of China, 2000; Chen and Zhang, 2000; National Bureau of Statistics of People’s Republic of China, 2000; Liu, 2001). The data are first pre-processed as fellows: (1) converting NPP into vector data, (2) overlaying Chbnd with GridRoad and GridRail by Intersect and creating a data layer, ChBndNew, (3) adding fields, CityFlag for urban code and rural code and CityArea for areas of urban districts, in Chzh, (4) overlaying Chzh with ChBndNew by Intersect and creating a data layer, ChCity，(5) overlaying NPP with ChCity by Intersect and creating a new data layer, NppNew. The SPD grids are generated on the basis of the new data layer in terms of equation (3). Text file of calculated result is converted into point vector data and grid data is created from the point vector data.

The result (as seen in Figure 1) shows that the highest SPD almost centralized in two regions that are Pearl River Delta and the triangle zone taking Beijing-Tianjin-Tangshan urban agglomeration, Shanghai-Nanjing-Hangzhou urban agglomeration, and Zhengzhou city as its three vertexes (BSZ). The area surrounding Wuhan city and the one surrounding Shenyang city have higher SPD. The BSZ triangle zone is trending to a pentagon taking Shanghai-Nanjing-Hangzhou urban agglomeration, Wuhan city, Xian city, Beijing-Tianjin-Tangshan urban agglomeration and Shengyang-Dalian urban agglomeration as its five vertexes.

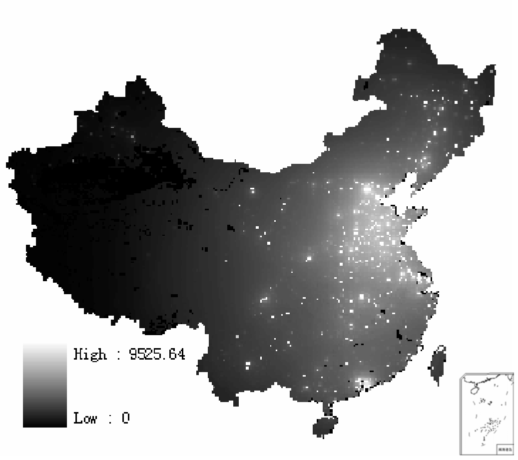

Figure 1. Simulated population density of China in 2000

(Unit: persons per square kilometer)

3. RECOMMENDATIONS

The model proposed in this paper is a case of multi-source information fusion, in which relation pattern among information from various sources is simulated. For multi-scale information fusion, another grid-generation based model in the light of surface fundamental theorem is useful (Yue and Liu, 2001).

The existing relative models can be classified into spatial interpolation models and digital terrain models. Issues on errors of digital terrain models and spatial interpolation models have been important research topics since the late 1960s and many methods for analyzing and measuring errors have been developed (Wise, 2000). However, the error problem is not attacked at the root. Although relative studies have found that slope, aspect and curvature are the most important variables for a surface (Evans, 1980), these variables are not used in formulation of the relative models. In fact, the first and the second fundamental forms are determinants of a surface, while the slope, aspect and curvature only are determinants of the thalweg of a surface according to differential geometry (Henderson, 1998). The grid-generation based model in the light of the fundamental theorem of surfaces is able to integrate theory of differential geometry with expertise, remote sensing information and monitoring information at points. It is an alternative way to solve the error problem of the existing relative models at the root. In addition, the grid-generation based models have two major advantages that are rapid computation of the grids and direct control over grid point locations.

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