

矢量瓦片地图关键技术研究

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摘要:针对栅格瓦片地图在高清屏显示、数据更新、与用户交互等方面存在的性能瓶颈,引入能解决上述问题的矢量瓦片地图。介绍矢量瓦片地图技术实现原理、数据标准,对矢量瓦片的数据组织模型、数据编码规则和地图渲染引擎的关键技术进行阐述,提出天地图·珠海提供矢量瓦片地图服务的技术思路。

关键词: 矢量瓦片; 地图; 天地图; Mapbox; WebGL

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近几年计算机技术快速发展,特别是浏览器渲染技术(如WebGL)的出现,让浏览器可以借助系统显卡展示2D和3D地图,还能创建复杂的导航和数据视觉化效果,矢量瓦片地图逐渐被各地图服务平台采用^[1]。

1 矢量瓦片地图

1.1 矢量瓦片地图服务的原理

矢量瓦片类似于栅格瓦片,以多层次模型将矢量数据分割成为矢量要素描述性文件存储于服务器端,在客户端根据指定的样式进行渲染绘图。矢量瓦片与栅格瓦片的不同之处是单个矢量瓦片存储投影在一个四方形区域的几何信息和属性信息,而不是预先渲染的栅格图片。矢量瓦片地图的实现模型如图1所示。首先需要将矢量数据的几何信息和属性信息分割为一组矢量瓦片存储在服务器端,客户端根据地图显示范围和样式文件定义的数据源通过分布式网络获取矢量瓦片、地图标注字体、图标等数据源,然后根据样式文件定义的地图表达规则在客户端即时渲染输出地图。

1.2 矢量瓦片数据标准

目前矢量瓦片尚无统一数据标准,Mapbox基于Google protocol buffers 制定的开源矢量瓦片数据标准MAPBOX VECTOR TILE SPECIFICATION,是目前较为通用的矢量瓦片数据标准,已被多个公司和组织采用^[2]。早期Mapnik也制定了矢量瓦片数据标准(mapnik-vector-tile)^[3-4]。

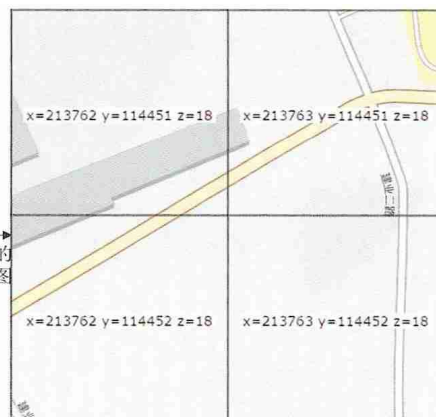
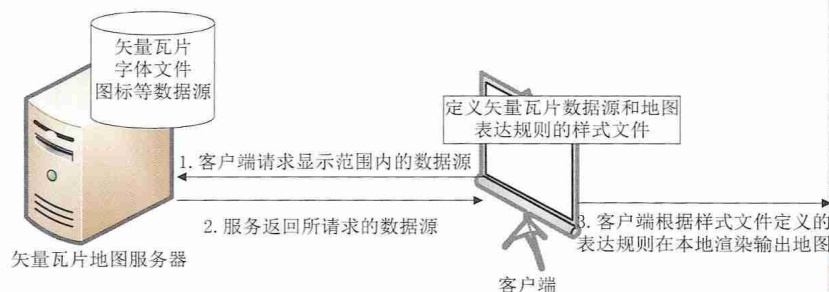
2 矢量瓦片地图关键技术

2.1 矢量瓦片数据的组织

矢量瓦片数据组织可分为两个层次:①地图表达范围内的瓦片数据集组织模型;②单个瓦片内要素的组织模型。

2.1.1 瓦片数据集的组织模型

矢量瓦片数据集的组织模型可参考栅格瓦片金字塔模型;可通过自定义矢量瓦片的大地坐标系、投影方式和瓦片编号方案实现任意精度、任意空间位置与矢量瓦片的对应关系^[5]。为了与目前的栅格瓦片相关服务规范(如:OGC WMTS等)相兼容以及便于将



输出的矢量瓦片地图

图1 矢量瓦片地图的实现模型

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矢量瓦片转换为栅格瓦片，矢量瓦片一般采用与栅格瓦片相同的投影方式和瓦片编号方式。

以 Mapbox 矢量瓦片为例，其默认的大地坐标系为 WGS-84，投影方式为球面墨卡托（Web Mercator），

瓦片编号采用 Google 瓦片方案^[6]。因此，Mapbox 矢量瓦片的大地坐标系、投影坐标系、像素坐标系和瓦片坐标系与栅格瓦片一致，如图 2 所示。各缩放级别下瓦片的数量和单个瓦片代表的空间大小如表 1 所示。

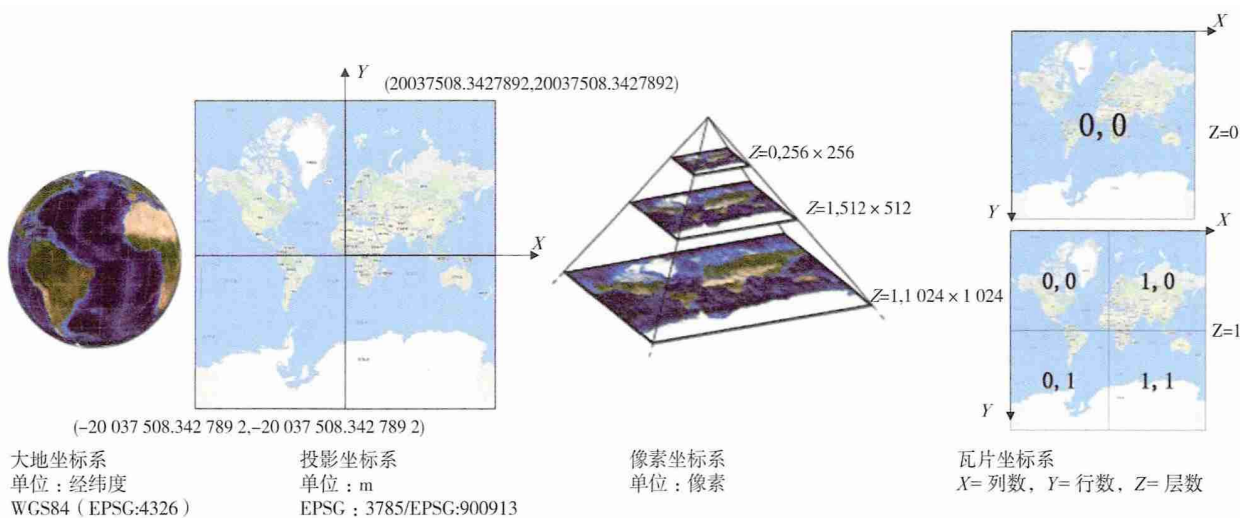


图 2 矢量瓦片地图的坐标系统

表 1 各缩放级别下瓦片的数量和单个瓦片的大小对照表

缩放级别	瓦片金字塔数量	瓦片大小/°	瓦片大小/m
0	$1 \times 1 = 1$	$360^\circ \times 170.1022^\circ$	$40\,075\,016.685\,578\,4 \times 40\,075\,016.685\,578\,4$
1	$2 \times 2 = 4$	$180^\circ \times 85.0511^\circ$	$20\,037\,508.342\,789\,2 \times 20\,037\,508.342\,789\,2$
2	$4 \times 4 = 16$	$90^\circ \times 42.5256^\circ$	$10\,018\,754.171\,394\,6 \times 10\,018\,754.171\,394\,6$
n	$2^n \times 2^n = 2^{2n}$	$360/2^n \times 170.1022/2^n$	$40\,075\,016.685\,578\,4/2^n \times 40\,075\,016.685\,578\,4/2^n$

2.1.2 单个瓦片内要素的组织模型

单个矢量瓦片在逻辑上可以通过图层组织要素信息。每个图层所包含要素的几何信息和属性信息在逻辑上分开存储。以 Mapbox 矢量瓦片为例，其逻辑存储结构如图 3 所示。几何要素分为点、线、面和未知要素类。其中未知要素类是 Mapbox 特意设置的一种要素类型，解码器可以尝试解码未知的要素类型，也可以选择忽略这种要素类型的要素。元数据信息又分为图层属性和要素属性。每块矢量瓦片至少包含一个图层，每个图层至少包含一个要素。

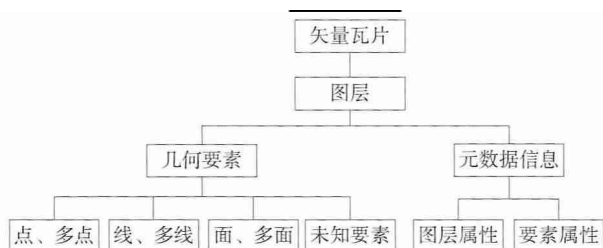


图 3 矢量瓦片的逻辑存储结构

矢量瓦片的物理模型是瓦片属性信息和位置信息在存储过程中的具体表现形式^[4]。描述矢量瓦片属性信息和几何位置信息的文件常有：GeoJson (.json)；TopoJSON (.topojson) 和 Google Protocol Buffers (PBF)。其中 GeoJSON 是一种基于 Javascript 对象表示法的地理空间信息数据交换格式，易于阅读，通用性强，大多数软件可以直接打开，但存储地理数据较多时易产生

冗余信息。TopoJSON 是在 GeoJSON 基础上对共享边界几何要素拓扑编码，减少冗余信息的一种优化数据格式，被 Mapzen 推荐作为矢量瓦片的存储格式。Google Protocol Buffers (PBF) 是一种轻便高效的结构化数据存储格式，Mapbox 矢量瓦片采用 PBF 格式组织单个瓦片内要素的信息。为了便于矢量瓦片数据集的网络传输和数据库存储，可以将矢量瓦片数据集打包生成矢量瓦片包，常用的有 ArcGIS 矢量瓦片包（VTPK 格式）和可存储到 SQLite 数据库的 MBTiles 格式等。

2.2 基于 Google Protocol Buffers 矢量瓦片的编码规则

Mapbox 矢量瓦片采用 Google Protocol Buffers 进行编码，相比 GeoJSON 格式的矢量瓦片文件体积更小，解析速度更快。

2.2.1 几何信息编码

GeoJSON 格式的矢量瓦片文件记录要素几何信息一般采用原始经纬度坐标。PBF 格式的矢量瓦片存储几何信息所用坐标系定义为以瓦片左上角为原点，X 方向向右为正，Y 方向向下为正，坐标值以格网数为单位。单个矢量瓦片默认的格网数为 $4\,096 \times 4\,096$ ，即使 4K（屏幕分辨率为 $4\,096 \text{ px} \times 4\,096 \text{ px}$ ）的高清屏上只显示一张矢量瓦片也不会出现类似于栅格瓦片的锯齿效果。屏幕分辨率越高，可以提供相应的提高瓦片格网数量，以精确记录瓦片内要素的几何位置信息。

假定一张矢量瓦片格网数定义为 20×20 , 瓦片的左上角是坐标原点 $(0,0)$, 如图 4 所示。该瓦片内的一条红色线要素的 3 个顶点坐标分别为 1 $(2, 2)$ 、2 $(2,10)$ 、3 $(10,10)$ 。首先将线要素的几何信息转换为指令集表达, 然后再将指令存储为 32 位无符号整数存储到 PBF 文件中, 如图 4 所示。

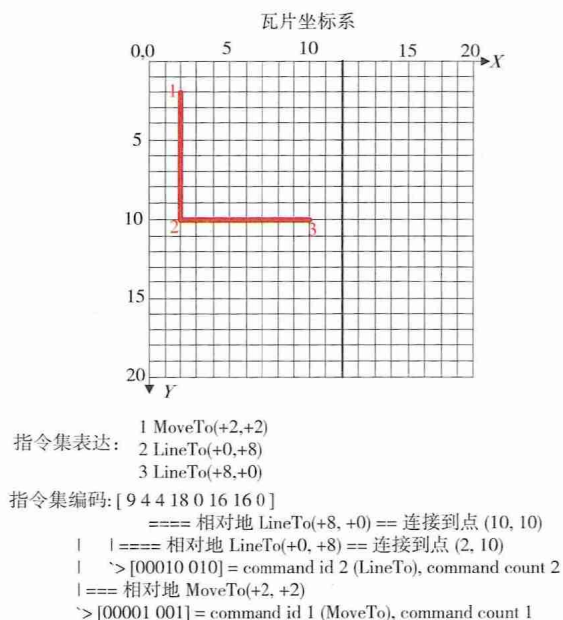


图 4 矢量瓦片的几何信息编码

2.2.2 属性信息编码

PBF 格式的矢量瓦片要素属性被编码为 tag 字段中的一对整数。如图 5 所示, 左侧为原始 Geojson 格式表达两个要素的属性信息格式, 右侧为 PBF 格式。要素 1 的属性字段“hello”, 属性值为“world”, 在 PBF 格式中用一对整数“0,0”表示, 第一个整数表示 key 在



图 5 矢量瓦片的属性信息编码

其所属图层的 keys 列表中的索引号 (以 0 开始); 第二个整数表示 value 在其所属图层的 values 列表中的索引号 (以 0 开始)。通过比较可以发现, 存储大量的重复字段名称和属性值的要素信息时, PBF 格式能够很好地避免重复信息的产生。

2.3 矢量瓦片地图渲染引擎

OpenGL、WebGL 等客户端图形渲染技术的发展, 推动了地图渲染引擎的快速发展。WebGL 是一项可以在浏览器中流畅展示 3D 模型和场景的一种技术, 它使用 javascript 作为编程语言, 调用浏览器支持的 3D 绘制函数, 来实现 3D 模型和场景的展现。因为浏览器实现了 OpenGL ES 的规范, 这套规范可以直接使用指令操作显卡, 使显卡渲染的 3D 世界, 直接反映到浏览器中。WebGL 视觉成像原理如图 6 所示, 客观世界的地物通过计算机能识别的编码规则定义为虚拟的 3D 模型, 通过一组参数改变视点 (Camera) 位置实现不同角度虚拟的 3D 模型在显示屏上成像输出。

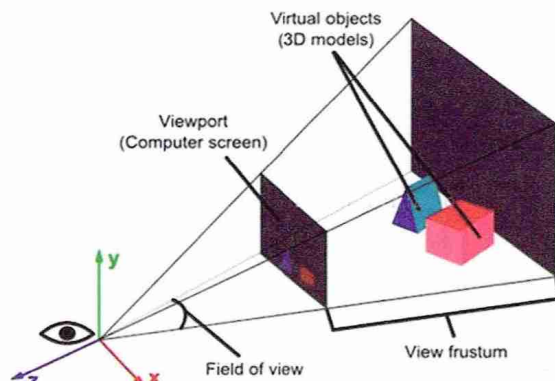


图 6 WebGL 视觉成像原理

OpenGL、WebGL 是底层 3D 绘图技术标准, 为了便于地图的渲染输出, Mapzen 采用 Tangram 作为地图渲染引擎。Tangram 是一个开源的 3D 渲染引擎, 专门用于绘制地图, 使用 OpenGL 图形 API。它能够解析各种来源的矢量数据, 然后在客户端实时渲染生成带有几何图形、文字标注、图示符号的 3D 场景地图^[7]。Tangram 提供了两种开发包: 浏览器渲染引擎 (Tangram-JS) 和移动终端渲染引擎 (Tangram-ES)。Mapbox 采用 Mapbox GL 作为地图渲染引擎, 类似于 Tangram, 提供了浏览器渲染引擎 (Mapbox GL JS) 和移动终端渲染引擎 (Mapbox GL Native)^[8]。

Mapbox 样式文件是定义地图视觉效果的文件, 它定义了绘制地图数据源、绘制顺序以及绘制样式等规则。根据样式文件的信息, 利用 Mapbox GL JS 可在浏览器中实时渲染出互动性强的 3D 场景地图。在 HTML 中插入如图 7 所示的 Javascript 代码, 便可实现矢量瓦片地图实时渲染输出。


```

<!DOCTYPE html>
<html>
<head>
  <script src='https://api.tiles.mapbox.com/mapbox-gl-js/
v0.31.0/mapbox-gl.js'></script>
  <link href='https://api.tiles.mapbox.com/mapbox-gl-js/
v0.31.0/mapbox-gl.css' rel='stylesheet' />
</head>
<body>
  <div id='map' style='width: 400px; height: 300px;' />

  <script>
    mapboxgl.accessToken = '<your access token here>';
    var map = new mapboxgl.Map({
      container: 'map',
      style: 'mapbox://styles/mapbox/streets-v9'
    });
  </script>
</body>
</html>

```

a HTML中调用 Mapbox GL JS 代码

```

{
  "version": 8,
  "name": "Mapbox Streets",
  "sprite": "mapbox://sprites/mapbox/streets-v8",
  "glyphs": "mapbox://fonts/mapbox/{fontstack}/{range}.pbf",
  "sources": { ... },
  "layers": [ ... ]
}

```

b Mapbox 样式文件基本结构

图7 基于 Mapbox GL JS 浏览器输出矢量瓦片地图的示例代码

3 制作矢量瓦片地图的技术流程

通过 Openstreetmap 地图数据源提取珠海市范围地图数据, 利用开源软件制作基于 Mapbox 矢量瓦片数据标准的地图服务资源。主要技术流程如图8所示。创

建矢量瓦片的工具采用 Tippecanoe, 矢量瓦片的空间基准采用 WGS-84, 瓦片组织方案采用 Google 瓦片方案。采用 SpatialServer (PGRestAPI) 作为服务器端发布地图服务, 客户端采用 Mapbox GL JS 调用矢量瓦片地图服务在浏览器输出矢量瓦片地图。

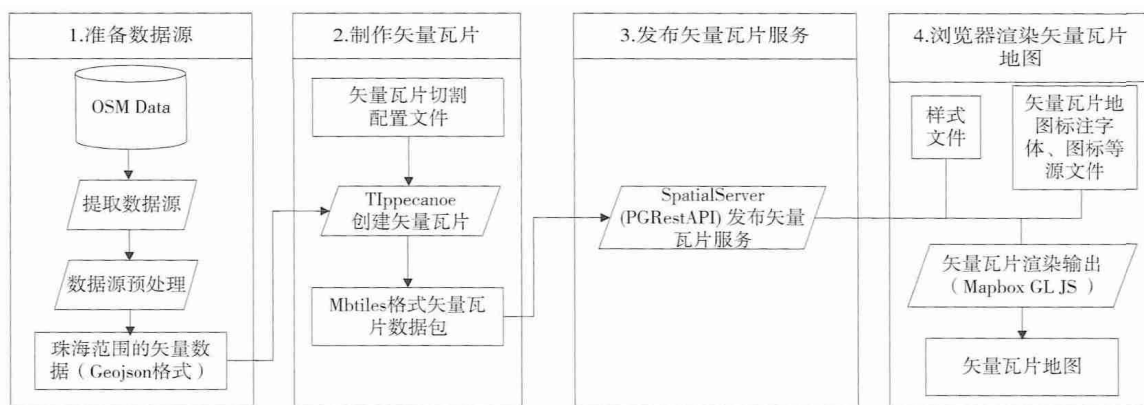


图8 制作矢量瓦片地图的技术流程

4 结语

矢量瓦片地图作为一种新兴的互联网电子地图服务方式, 相比传统的栅格地图具有显示效果好、地图互动性强、无插件实现二三维一体化、一源多样(一套数据源生成多种样式地图)、瓦片体积小、更新效率高等诸多优点。目前天地图·珠海在政务版和公众版提供的矢量电子地图、晕渲电子地图和影像电子地图(注记图层)若升级为矢量瓦片地图提供服务, 还要进一步研究现有的三维模型数据融入矢量瓦片提供二三维一体化的地图展示、空间查询分析以及结合天地图数据融合项目实现多尺度数据自适应更新、无极缩放显示等技术。

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Research on Key Technologies of Vector Tiles Map

by CHEN Juping

Abstract This paper introduced the principle and the standards of vector tiles map, which could solve the raster tiles map performance bottlenecks in aspect of displaying on HD screen, updating data, interacting with users, etc. And then, the paper described the data organization model, data encoding rules and map rendering engine of vector tiles map. Finally, this paper presented the technical scheme that MapWorld·Zhuhai providing vector tiles map services.

Key words vector tiles map, map, MapWorld, Mapbox, WebGL (Page:44)

User Positioning Accuracy Assessment of BDS Basic Service

by YANG Zili

Abstract This paper focused on the positioning accuracy of BeiDou dual-frequency receiver users in the open service provided by BeiDou, and analyzed PDOP distribution and UERE series. The results show that under BeiDou GEO/IGSO/MEO mixing constellation current conditions, the users' PDOP values vary in different area, and under the broadcast ephemeris current condition, the users' average UERE reach about 1 m. In BeiDou open service, based on the broadcast ephemeris and dual-frequency observations, common receiver user's horizontal accuracy is 2.01 m, elevation accuracy is 3.11m, which means BeiDou has achieved high accuracy and can meet users' need in traffic guidance.

Key words BeiDou, positioning accuracy, PDOP, UERE (Page:48)

Median Filter with Gaussian Weighted in Remote Sensing Image and Its Fast Implementation

by DENG Shaoping

Abstract In this paper, an improved median filtering algorithm with Gaussian weighted for the neighboring pixels was proposed for the remote sensing image. And then, this algorithm's fast version was implemented by C language. Finally, the general, optical and SAR remote sensing images were used to test the new method. The results demonstrate that this algorithm has the better noise inhibition performance, while the computing efficiency is improved much greater than the classic median filter.

Key words median filter, fast implementation, remote sensing, Gaussian weighted (Page:50)

Analysis of the Urban Green Dynamic Change and the Driving Force Based on GIS and RS

by LI Jiangping

Abstract Based on the principle and method of landscape ecology, this paper used RS and GIS technologies to analysis the dynamic changes and driving factors of urban green space landscape pattern of Hefei City in recent 20 years. The result shows the land use in the study area changed dramatically from 1995 to 2014. Among them, the urban green space area is continuously increasing, accounting for the proportion of the study area increased from 12.3% in 1995 to 25.8% in 2014. At the same time, the landscape pattern of urban green in Hefei City changes obviously. From 1995 to 2002, the number and the density of urban green patch were increased, which indicated that the fragmentation was worsened, and from 2002 to 2014, the number and the density of urban green patch showed a downward trend, which indicated that urban green space pattern became aggregation in the study area. The main factors of the urban green dynamic changes are human factors, including urban population growth, rapid economic development and related forestation policy execution, etc.

Key words urban green, landscape pattern, remote sensing, GIS (Page:53)

Research on 3D Ground Excavation Algorithm Based on ArcEngine

by WANG Haitao

Abstract Aiming at the problem of pipeline broken during the period of urban underground pipeline embedded, we proposed a algorithm for simulating urban excavation by using the topology checking interface and overlapping surface judging interface of ArcEngine component objects in 3D urban GIS system in this paper. And then, we introduced the key technical points and realization process of the algorithm in detail, and verified the feasibility and accuracy of the algorithm by experiments.

Key words ground excavation simulation, topology check, hollowing process, excavation range (Page:57)

Ecological Sensitivity Analysis of the Guanzhong-Tianshui Region Based on GIS

by CHENG Kunfeng

Abstract This article selected slope, elevation, land-use type, watershed, vegetation coverage index as eco-sensitive factors, and used analytic hierarchy process (AHP) to determine the weights of each eco-sensitive factor. The paper analyzed distribution of eco-sensitive situation in Guanzhong-Tianshui economic zone based on different spatial scales including pixel, administrative division and basin. The results show that the percentages of high sensitive area, moderate sensitive area, low sensitive area and insensitive area are 18.81%、31.61%、44.47% and 5.11% respectively. Shangluo City is in the highest eco-sensitive situation, Yangling District is in the lowest eco-sensitive situation, and Qianyou Basin is in the highest eco-sensitive situation and Wei River Basin (Longmen to Shanmenxia Gorge and Xianyang to Tongguan) are in the lowest eco-sensitive situation. At last, the paper came out suggestion about eco-environment selective protection and construction for authorities in Guanzhong-Tianshui economic region. This study can provide a reference basis for related departments to formulate development strategies.

Key words GIS, Guanzhong - Tianshui economic region, hierarchy analysis, ecological sensitivity, multi-scale (Page:60)

Application of Natural and Environmental Resources Database in Grenada

by SUN Jiakuo

Abstract Taking natural and environmental resources in Grenada as the research object, collecting a large number of related original data, we used GIS to organize data at first. And then, we established a series of effective classification coding rules, and converted all space elements to raster and vector data format, then edited into database. Finally, we established a Grenada's natural and environmental resources exclusive database which had completed information, to facilitate query information and statistics. On the basis of this, we used 3D visualization software ArcScene to analysis the fundamental data of Grenada such as rainfall and landform. The results could be helpful to the further research.

Key words GIS, spatial database, natural resource and environment, analysis (Page:65)

Research on the Delimitation of Construction Land Control Zone of Jinpu New Area in Dalian

by PEI Qian

Abstract According to the weakness of the construction land control zone in the current land use general planning, this paper designed a method for delimit the construction land control zone based on GIS. According to different regulation purposes, combining with the actual situation of Jinpu New Area, making full use of mathematical models and the powerful spatial analysis ability of MapInfo, the paper quantitatively defined the areas of the construction land control zone, and compared with the current control zone drawing of Jinpu New Area. Finally, this paper analyzed the reasonable delimitation of the construction land control zone in Jinpu New Area planning period, and put forward the delimitation method of the control zone in line with the actual development of the county.

Key words the construction land control zone, GIS, Jinpu New Area (Page:68)

Training Method for Map Using at the Actual Ground Based on Virtual Space Scene

by GAO Shuai

Abstract Starting from the present situation of the training about map using at the actual ground, this paper analyzed the characteristics and performance of virtual space scene, designed a virtual training method for map using at the actual ground, simulated topography cognition, map comparison and marching as the map shown, and set up a computer quantitative evaluation mechanism. The research shows that using the virtual space scene to train the map using at the actual ground, which can improve the informatization degree and the efficiency of training.

Key words virtual space scene, map using at the actual ground, topography cognition, map comparison (Page:71)

Technical Characteristics of the Suqian Cities and Towns Satellite Image Atlas

by HUANG Hongxian

Abstract This paper summarized the design idea of the Suqian Cities and Towns Satellite Image Atlas, and describes its technical characteristics. This Atlas made full use of the existing basic surveying and mapping results, and with the latest satellite images as the background, combined with the map form of the road and place names, reflected the urban geographical information and spatial layout.

Key words image atlas, cities and towns satellite image, technical characteristic (Page:73)

Research and Design of the Mobile Law Enforcement and Supervision System

by LU Gehua

Abstract At present, the fieldwork in after-authorization management is supported not enough in Xiangtan City urban-rural planning management information system. In order to solve the problem, this paper used the technologies of mobile communication, mobile GIS and GPS to design the mobile law enforcement and supervision system, which could implement the seamless connection between fieldwork and office work in law enforcement and supervision.

Key words after-authorization management, mobile law enforcement and supervision, mobile GIS, GPS (Page:75)

Design and Development of Huaguo Mount Guide System Based on SuperMap iMobile

by LIU Haipeng

Abstract We used SuperMap iMobile GIS components combined with Android development technology to design and develop the Huaguo Mount guide system in the mobile terminal, and realized the main function and the using of desktop data in this article. This system can run on the mainstream Android devices and meet the certain tourism's demands.

Key words Android, mobile GIS, SuperMap iMobile, tourism (Page:77)

Improved Haze Removal Algorithm Based on Graph-cut

by LI Nana

Abstract The images captured in haze are poor visually, which seriously affected the reliability and robust of visual surveillance system. In order to improve the contrast and sharpness of images, considering that different scenes were different in depth, we used graph-cut to segment images. After that, we obtained the fog concentration diagrams in each area based on dark-channel prior method. Finally, according to DOS theory, we removed the fog concentration diagram from the original image. With a series of experiments, we concluded that the improved algorithm is effective in improving the quality, contrast and sharpness of images.

Key words graph-cut, image segmentation, haze removal, DOS (Page:80)