

城市水资源 GPS 网的建立



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摘要: 结合利用 CORS 虚拟技术, 阐述了城市水资源勘测 GPS 网的布设及数据处理方法, 并对精度进行了分析, 结果表明在确保成果精度和可靠性的前提下, CORS 虚拟技术可以节省成本投入, 提高生产效率, 从而对丰富 CORS 服务具有重要意义。

关键词: CORS; GPS 控制网; 虚拟基站; 数据处理

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苏州地处长江和太湖下游, 境内地势平坦, 水网密布, 河道纵横交错, 有各级河道 20 000 多条, 湖泊星罗棋布, 有大小湖泊 320 多个, 水域面积 3 609 km², 防洪排涝标准偏低, 人口密集, 防汛抗洪的进退余地较小, 防汛抗洪形势严峻。为了能及时掌握水情变化, 提供准确及时的水文信息, 在现有分布于大市范围的水文监测基准点基础上, 有必要建立一个全天候、连续、统一的水文监测基准框架控制网。随着苏州市连续运行卫星定位综合服务系统的投入稳定运行, 利用虚拟技术可以快捷、高效地建立一个基于苏州城市动态测绘基准的控制网, 以满足水文监测的动态需要, 加强城市水文设施建设, 提高城市水文的现代化水平, 为苏州城市防汛决策和工程运行调度提供准确及时的水文信息。

1 GPS 网设计与数据采集

1.1 GPS 网设计

GPS 控制网设计时平面坐标系统启用了新苏州独立坐标系, 该坐标系统建立时充分考虑了实现苏州市统一坐标基准的目标, 选择新的投影中央子午线和投影高程面, 使整个苏州市的投影变形量达到最小, 满足城市测量规范规定的 2.5 cm/km 范围^[1]。

网形布设时利用苏州市连续运行卫星定位综合服务系统与现有的吴淞系高程控制点, 采用 CORS 虚拟技术, 使用单台套 GPS 进行观测, 以扩展 GPS 网, 构网采用“虚拟混合边连式”的方法进行, 观测要求按照城市 D 级控制网进行。由于现有吴淞高程成果资料之间存在着不同期测绘等情况, 因此通过本次 GPS 控制网布测拟使吴淞高程的内部拟合精度能达到±5 cm。

CORS 虚拟技术^[2]是利用 CORS 基准站的原始观测数据, 计算任意历元 GPS 卫星的三维位置以及基准站间基线的轨道误差、对流层延迟及电离层延迟; 然后根据网内任意点位置和其他设定计算该点和可视卫星之间的距离以及相关空间误差, 从而获取虚拟基站的仿真观测数据^[3]。在生产实践中可以应用虚拟观测数据, 同时投入 2 台, 甚至 1 台 GPS 设备, 就能灵活构建出网形几何强度较高、具有非同步图形闭合条件、良好自检能力以及点位中误差均达到 mm 级的边连式 GPS 控制网, 确保实际观测控制点的质量和可靠性^[4]。

1.2 数据采集

控制网外业观测严格按设计要求进行, 所有野外记录均在现场完成, 观测记录装订成册后上交。实际观测过程中, 前 4 天均只有 1 台仪器参与观测, 最后 2 天有 2 台仪器参与观测, 2 台仪器虽然有零星构成同步基线, 但均不采用, 外业观测展点图见图 1。

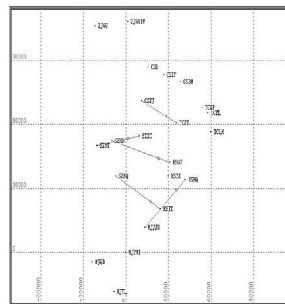


图 1 “单台”GPS 外业观测展点图

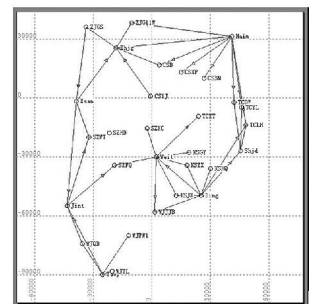


图 2 引入参考网站后基线网图

结合项目特征为“单台”套 GPS 作业的控制网, 引入苏州市连续运行卫星定位综合服务系统的参考站点, 所购的基线网图见图 2。

在数据处理时, 根据引入参考站点后的网形结构,

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利用 CORS 虚拟技术内插出 9 个虚拟观测点,虚拟点观测条件按照 C 级网要求。物理(架站)观测点与虚拟观测点构成的基线网形图见图 3。

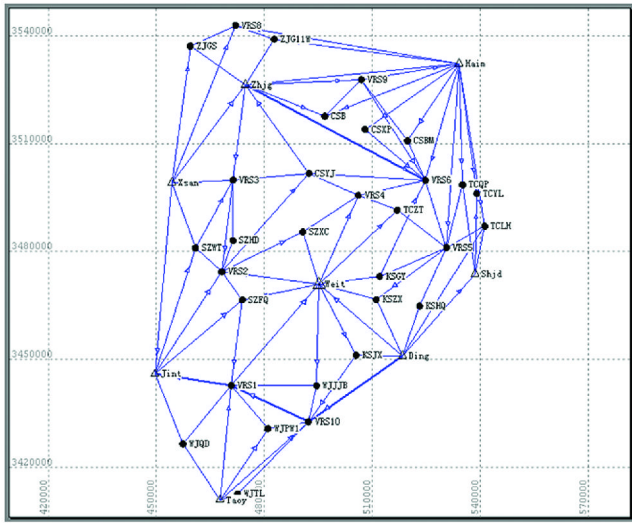


图 3 引入虚拟观测点后基线

2 数据处理与精度分析

2.1 基线检核

基线处理是利用多个测站的 GPS 同步观测数据,确定这些测站之间坐标差的过程。处理结果将作为后续 GPS 基线向量网平差的观测值,同时也是进行基线质量控制的依据。GPS 基线向量的处理采用随机软件 TGO V1.63 版。

各时段向量的重复性反映了基线解的内部精度,是衡量基线解质量的一个重要指标。本控制网中存在 4 对重复基线。根据 GB/T18314-2001《全球定位系统(GPS)测量规范》规定:复测基线的长度较差,不应超过规定: $ds \leq 2\sqrt{2}\sigma$ 。

表 1 重复基线长度较差检验统计/m

序号	重复基线位置差 ds	重复基线位置差限值 $2\sqrt{2}\sigma$
g VRS10	0.006 4	0.091 3
VRS1 Jint	0.005 3	0.062 4
VRS10 VRS1	0.026 9	0.068 4
Zhjq VRS6	0.067 7	0.161 0

从表 1 可知,控制网中的 4 条重复基线均满足规范要求,说明控制网的外业观测数据质量较好。

GPS 闭合环闭合差的大小可反映 GPS 外业观测质量和基线解算质量的可靠性。

根据 GB/T18314-2001《全球定位系统(GPS)测量规范》规定独立闭合环的坐标闭合差应满足:

$$W_x \leq 3\sqrt{n}\sigma, W_y \leq 3\sqrt{n}\sigma, W_z \leq 3\sqrt{n}\sigma, W_s \leq 3\sqrt{3n}\sigma$$

式中, n 为闭合环边数; σ 为相应级别规定的精度。

独立基线组成的异步环共 27 个,最弱异步环精度

为 1.016×10^{-6} ,其余闭合环 10^{-6} 均低于 1×10^{-6} ,所有独立闭合环闭合差均满足规范要求。

由重复基线和独立闭合环的相对精度表明,基线处理合理,结果可靠,没有含明显粗差的基线向量存在,所挑选基线可作为基线观测量参与网平差计算。

2.2 WGS84 坐标系下的三维无约束平差

三维无约束平差的主要目的有:进行粗差分析,发现观测量中的粗差并消除其影响;调整观测量的协方差分量因子,使其与实际精度相匹配;对网的整体内部精度进行检验和评估。後

根据规范要求,在无约束平差中,基线向量的改正数 ($V_{\Delta x}, V_{\Delta y}, V_{\Delta z}$) 绝对值应满足:

$$V_{\Delta x} \leq 3\sigma, V_{\Delta y} \leq 3\sigma, V_{\Delta z} \leq 3\sigma$$

当超限时,可认为该基线或其附近存在粗差基线,应采用软件提供的方法或人工方法剔除粗差基线,直至符合上式为止。

GPS 三维无约束平差的结果,客观地反映了整个 GPS 网的内部符合精度。

表 2 基线向量无约束平差改正数绝对值统计/m

序号	最大值	限差	最小值	平均
X 方向改正数	0.058	0.142	0	0.003
Y 方向改正数	0.085	0.142	0	0.004
Z 方向改正数	0.073	0.142	0	0.003

从表 2 可知,基线分量的改正数都较小,说明观测质量较好,基线解的精度较高。

2.3 WGS84 坐标系下的三维约束平差

约束平差的目的是引入外部基准,其将所有独立基线向量及其经调整后的协方差阵作为观测量,平差消除因星历和网的传递误差引起的整网在尺度和方向上的系统性偏差。

在约束平差中,基线向量的改正数与剔除粗差后的无约束平差结果的同名基线相应改正数的较差 ($dV_{\Delta x}, dV_{\Delta y}, dV_{\Delta z}$) 应满足:

$$dV_{\Delta x} \leq 3\sigma, dV_{\Delta y} \leq 2\sigma, dV_{\Delta z} \leq 2\sigma$$

当超限时,可认为作为约束的已知坐标、距离,已知方位角与 GPS 网不兼容,应采用软件提供的或认为的方法剔除某些误差较大的约束值,直至符合上式为止。

三维约束平差以唯亭为三维控制点,其他参考站点的平面方向控制基准。

表 3 基线向量约束平差改正数较差绝对值统计/m

序号	最大值	限差	最小值	平均
X 方向改正数	0.024	0.120	0	0.000 2
Y 方向改正数	0.016	0.103	0	0.000 1
Z 方向改正数	0.021	0.107	0	0.000 4

由表 3 可知,约束平差后的基线改正数与之前无

约束平差后的同名基线改正数较差优于规范规定指标，完全满足技术设计要求。

2.4 点位误差统计

在 WGS84 基准下三维约束平差后点的点位精度中误差，见表 4，虚拟检核点位坐标比较见表 5。

表 4 点位精度中误差统计/m

序号	最大值	最小值	平均
纬度方向	0.017	0.001	0.007
经度方向	0.020	0.001	0.008
大地高方向	0.075	0.011	0.030

表 5 虚拟检核点位坐标比较

点名	B/	L/	H/m
VRS1	-0.000 20	0.000 30	0.014
VRS2	0.000 02	0.000 06	-0.001
VRS3	-0.000 03	0.000 16	0
VRS4	-0.000 20	-0.000 05	-0.014
VRS5	0.000 32	0.000 08	-0.013
VRS6	-0.000 01	-0.000 15	-0.003
VRS8	0.000 09	0.000 10	-0.026
VRS9	0.000 04	-0.000 02	-0.023
VRS10	-0.000 03	-0.000 01	0.006

由表 4,5 可知，虚拟检核中 VRS5 在纬度方向上的偏差最大，投影到平面坐标上 x 方向的偏差为 0.010 m，满足设计要求。

2.5 坐标转换

利用苏州市 2004 年建立的苏州市 GPS 首级城市扩展控制网转换参数，使用布尔莎模型，确定统一的投影高程面，将基于 WGS84 椭球的经纬度成果转换至新苏州独立坐标系成果；同时对吴淞高程系成果采用空点法，以求得基于连续运行参考站的最优转换参数结果。利用公式 $\sqrt{\frac{v^*v}{n-1}}$ 计算得到高程点的内附合精度为 4.5 cm，满足设计要求的 ±5 cm。

3 结 语

现在很多省市纷纷建立了高时空分辨率、高效率、

高覆盖率的连续运行参考站综合服务系统和厘米级区域似大地水准面相结合的高精度、动态的、三维大地测量基准框架的现代测绘基准体系^[5-7]。在城市 GPS 控制网中利用连续运行参考站综合服务系统，引入 CORS 虚拟技术，建立虚拟基站是一种高效、快捷的方法，通过本次城市水资源勘测 GPS 网的建立，结果表明：

1) 在确保解算成果质量，解算可靠性的基础上，基于 CORS 虚拟技术相比传统方式布网可以节省观测成本，解决了生产单位在投入观测仪器数量方面的限制，提高了投入产出的生产效益。

2) 城市水资源勘测 GPS 网的建立，解决了全市范围内的不同投影中央子午线带来的投影变形，达到了测绘“一张图”工程的目的，同时也为今后从吴淞高程系转换为黄海高程系的进一步优化创造了条件。

3) 基于 CORS 虚拟技术布设控制网具有可靠性高、布设网形灵活的技术特点，在今后的 GPS 定位技术建网中可以广泛地加以推广和应用，以提高城市 GPS 应用的水平。

参考文献

- [1] 唐文刚,奚长元. 苏州市 GPS 城市控制网的建立与精度分析[J]. 测绘信息与工程, 2004, 29(6): 34-36
- [2] 陈中新,朱丽强,吴栋. 虚拟基站网形结构对 GPS 控制网精度的影响[J]. 地理空间信息, 2010, 8(4): 25-27
- [3] 韩保民,欧吉坤,曲国庆. GPS 观测数据的模拟研究[J]. 武汉大学学报: 信息科学版, 2005, 30(3): 246-250
- [4] 陈中新,奚长元,朱丽强. 基于 CORS 虚拟技术建立任意图形结构 GPS 控制网的研究与实践[A]// 华东六省一市测绘学会第十二次学术交流会论文集[C].
- [5] 史照良,沈飞. 江苏省现代大地测量基准的建立方案探讨[J]. 测绘通报, 2007(9): 26-28
- [6] 刘士宁. 连续运行参考站(CORS)系统在城市管理中的应用[J]. 测绘与空间地理信息, 2009, 32(5): 6-8
- [7] 过静璐,王丽,张鹏. 国内外连续运行基准站网新进展和应用展望[J]. 全球定位系统, 2008(1): 1-10

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- [3] 施一民. 现代大地控制测量[M]. 北京: 测绘出版社, 2008
- [4] 欧朝敏,黄梦龙. 地方坐标到 2000 国家大地坐标转换方法研究[J]. 测绘通报, 2010(9): 26-28
- [5] 杨国清,张予东. 平面控制网四参数法坐标转换与残差内插[J]. 测绘通报, 2010(11): 48-50
- [6] 李美娟,李立瑞. 仿射变换模型在地形图坐标转换中的应用

- [J]. 勘察科学技术, 2009(1): 52-54
- [7] 王解先,邱杨媛. 高程误差对七参数转换的影响[J]. 大地测量与地球动力学, 2007, 27(3): 25-27
- [8] GB/T 14912-2005. 1 500, 1 1000, 1 2000 外业数字测图技术规程[S].

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Spatial Characteristics Detecting Model Based on TIN

by *LI Jingzhong*

Abstract The detection of spatial characteristics of GIS data is one of the key points in GIS theory research and engineering applications.

This paper present a delaunay triangulated irregular network based model, which adopt to all three geometry types (point, polyline and polygon) and could detect many types of spatial characteristics, such as distribution extent, density and skeleton for point cluster; bend structure for line object; bottleneck area and subgroup for polygon and poly-polygon. All these methods were tested and verified by related experiments; the results were promising and satisfy the basic principle of spatial cognition.

Key words GIS, spatial data mining, spatial cognition, delaunay triangulation (Page:26)

Discussion of Urban Road Network Evaluation System

by *XU Huichen*

Abstract There is not a systematic set of urban road network evaluation system in our country at present. Different planning need choose the proper evaluation method and set up the evaluation index system. Then took Xuzhou for example, set up the evaluation index system with the method of urban road network technology evaluation and made use of fuzzy logic model. The conclusion is: the urban road network of Xuzhou is good, however, at the aspect of road networks scale, it needs some improvements.

Key words road networks scale, evaluation system, evaluation index, fuzzy logic (Page:29)

Study of Information Dynamic Graphical on Disaster Response

by *ZHAO Hong*

Abstract To develop disaster contingency plans is most in text description, because of the single expression and the complexity of contents cause application difficulties and prone to understand the ambiguity. To solve this problem, this paper analyzed five spatial objects in disaster response were used to describe space phenomena features, and proposed spatial seven structured information elements owned by objects in disaster emergency were used in six kind expression of thematic map in disaster contingency, and researched the graphical mechanism of structured information elements, and emphasis the correspondence relationship between structured information elements and five variables of map symbol and the animation control during the process of dynamic graphics, and states design principles of symbol rendering. As a application example of forest fires and rescue team action, geographic data of which were tried to convert into dynamic graphical mapping data, which were symbolized by the drawing program of map symbol.

Key words disaster response, spatial information, map symbol, plotting (Page:32)

Real-time Method for Deformation Measurement on the Plane Based on TPS

by *HUI Guangyu*

Abstract During the intensity test of flight-testing, the results of deformation measurement is the base to evaluating whether it is risky for aviation and impedimental for control or not. This pater present a real-time method of deformation measurement based on the interface technology of GeoCOM, according to the theory of total station position and the method of data combination by excessive stations. Practice had proved that the method not only ensured data accuracy, provided deformation results and improved the work efficienty, but also had important guiding significance for the study of the measurement of plane bas-

ed on TPS(Total Position Station) in the future.

Key words deformation measurement, TPS; ordinate system of plane, coordinate system of TPS, real-time (Page:35)

Method for ADS40 Data Processing

by *ZHOU Junyuan*

Abstract This article introduced the characteristics of ADS40 data and its distinction with combine production practice. It studied ADS40 data handling methods and techniques in production process.

Key words ADS40, aerial photogrammetry, data handles (Page:39)

Design and Implementation of Thematic Cartography of Oil-Gas Geochemical Prospecting Based on GIS Data Warehouse

by *SUN Qiufen*

Abstract This paper present the design and implementation of thematic cartography for BTEX Data Warehouse of Oil-Gas Geochemical Prospecting based on GIS. It included the analysis of Data Streams in Automatic Aided Mapping System, the design of system scheme and the constructing of geologic symbol library in common use, saving and extracting spatial and attribute data in Data Warehouse, automatic theme filled and also the function for geologic thematic map's design and export. The result of the system test indicated that the system had commendably carried out the primary design, for it can effectively exhibit the result of BTEX Data Warehouse of Oil-Gas Geochemical Prospecting and has a good interaction capability between users and computer.

Key words GIS, BTEX, Data Warehouse, thematic map, symbol library (Page:41)

Methods for GPS RTK Positioning Accuracy and Quality Control

by *ZHANG Zhenjun*

Abstract Based on the experiments of GPS RTK observations and the analysis with error margin, pointed out its accuracy fixed position, aimed at the characteristics that the RTK measures, as to it's the credibility carried on analysis, and aimed at sexual of put forward the homologous quality control project.

Key words GPS, RTK, error margin, accuracy positions, quality controls (Page:44)

Method for Improving the City Large Scale Topographic Maps Coordinate Transformation Accuracy between the City Coordinate System and CGCS 2000

by *MA Wensheng*

Abstract For the purpose of translating the urban coordinate system to the CGCS2000 for large-scale topographic maps, the integral transformation productions using an uniform transformation model and parameters don't satisfy the accuracy. A method was put forward to solve the accuracy problem in the article. First, compatible analysis was made for all control points and gross error points were get rid of. Then remaining control points were build TIN and calculated partitioned transformation parameters. As a result, we could improve the partitioned transform accuracy. Last, a real example was used to testing. The result shows that method put forward in the thesis is feasible and can enhance the transform accuracy.

Key words large-scale topographic maps, China Geodetic Coordinate System 2000, transformation model, Triangulated Irregular Network (Page:47)

Establishment of Urban Water Resources Surveying GPS Network

by *LU Jianwei*

Abstract Combining CORS VRS technology, this paper introduced the related establishment and data processing method of an urban GPS network for water resources. Network accuracy was analyzed.

The result indicated that CORS VRS technology could save the cost and improve the production efficiency on the basis of precision and reliability. This also had the significance of developing CORS services.
Key words CORS , GPS control network , virtual station , data analysis (Page:50)

Google Earth in the Surveying and Mapping for Water Conservancy and Hydropower by *DOU Chunhong*
Abstract This paper analyzed the use of the power of Google Earth software, described in detail in the Water Conservancy and Hydropower Surveying and Mapping in a variety of practical applications, including hydraulic engineering section mapping, topographic mapping, control, network design, non-classified control point data management and other applications of the results etc., for the majority of Water Conservancy and Hydropower Surveying and Mapping workers.
Key words Google Earth, Hydraulic mapping, applications (Page:53)

Analysis of the Image Pyramid-based Connection Points Extraction by *YAO Zhiqing*
Abstract The paper introduced the function and principles of connection points extraction in aerial triangulation, compared the traditional and the new connection points extraction methods in aerial triangulation through experiments and analysed its advantages according to experimental results.
Key words aerial triangulation , image pyramid , corresponding image point (Page:56)

GDAL Multi-source Spatialdata Access Middleware by *LIU Changming*
Abstract Spatial data storage format and more features to the data sharing and interoperability difficult, often applied in the dynamic integration of data bottlenecks. Urgent need for a practical application can at any time, dynamic, and can be tightly integrated with the application conversion tools. In this paper, the use of middleware in the form design tool, and based on GDAL library implements the tool to complete the multi-source spatial data access, improves the dynamic integration of application system performance and verified through the application of the effectiveness of the proposed scheme.
Key words GDAL; Multi-source spatial Data; Conversion; Middleware; Dynamic (Page:58)

Application of SketchUp to Virtual Mountain Modeling by *LI Gang*
Abstract Based on SketchUp software three-dimensional modeling method quickly and efficiently, intuitive and convenient method of three-dimensional observation together with associated site photos and Google Earth satellite images, can be reproduced and simulate mountain scenes effectively. By way of example, a large area on the mountain for rapid modeling technology was researched using SketchUp and ArcGIS 3D Analyst software.
Key words mountain modeling , SketchUp software , three-dimensional visualization (Page:62)

Research of Interaction and Sharing Between Geo-Spatial Data of ESRI and AutoCAD Data by *SONG Chao*
Abstract In recent years, GIS presents a tendency of extending to other industry with rapid development. New demand of Geo-Spatial Data interaction between industries needs to be met. This paper made close analysis on the relation and difference of AutoCAD and Shape data, discussed the necessity and possibility of data sharing, concluding available methods and proposition, attempted to explore effective

measures to implement integrated application for ESRI Geo-Spatial data and AutoCAD data.
Key words ESRI Geo-Spatial data , AutoCAD data , interaction and sharing , effective method (Page:64)

Methods for GPS Satellite Orbits Interpolation by *LI Guangzhou*
Abstract International GNSS Service (IGS) provides the GPS orbits in 15 min; however, it is needed to be interpolated during GPS data processing. There are the conventional methods used for Standardization of GPS satellite orbits such as Lagrange Interpolation, Neville Interpolation, and Chebyshev Fitting. In this paper, the methods were used to interpolate the orbits provided by National Geodetic Survey. Results showed that the interpolating methods performs best with the 9 order, it performed worse with the order ascending after order 9.
Key words GPS , orbits interpolation , ephemeris (Page:67)

Construction of Three-dimensional Geographic Public Information Service Platform by *DENG Shihu*
Abstract With the problems of the three-dimensional geographic public information service platform construction, this paper analysed the relationship between the 3D GIS and 3D simulation. And based Chongqing city experiences it present several key issues about the construction of three-dimensional geographic information public service platform, such as 3D data model on 'volume' concept, 3D data classification and organization, massive 3D data management, data access between different platform, etc.
Key words 3D public service , simulation , 3D GIS data model (Page:69)

Temporal and Spatial Characteristics of Global Sea-level Changes Based on the Observation of Altimeter by *WANG Zhenzhen*
Abstract This paper analyzed the trend and distribution of global sea level by using the altimetric data from AVISO. Conclusions were as follows: the global sea level rise with the speed of 2.921mm, and varied with regions and seasons.
Key words sea-level height , curve-fitting , trend of sea-level height (Page:72)

Coordinate Transformation for Large-Scale Topographic Maps with Unknown Spatial Reference System by *HU Haiju*
Abstract Focusing on the coordinate transformation between an unknown spatial reference system and a certain coordinate system on the survey outputs of large-scale topographic map, the impact on transformation accuracy is testified by numerically simulating and calculating on various parameters. As a result, the Four-parameter 3D Transformation Model is not suitable for this kind of transformation while the Four-parameter Plane Model is superior. The influence of ellipsoid parameters on the latter is so small that totally can be ignored. Further to it, an approximate center meridian formula is deduced for the transformation based on the formulas of scale error of Gauss projection and Gauss projection. Finally, actual data are inputted to prove the feasibility of the preferred model.
Key words Unknown Spatial Reference System ; coordinate transformation ; center meridian ; ellipsoid parameter (Page:74)

Application of Ontology to Geographic Knowledge Base Construction by *CHEN Hu*
Abstract Geographic knowledge includes description, cognition and explanation of people to objective geographic existence. It is an important research to organize and manage geographic knowledge effectively and to realize knowledge sharing and reusing, in order to