



# 茂名城區 GPS 拟合高程精度的探讨

丁德生

(广东省国土资源测绘院, 广东 广州 510500)

摘要: GPS 控制网在联测水准点的基础上, 利用 GPS 水准高程来实现 GPS 网点的大地高向正常高转换, 其精度主要受所拟合的似大地水准面、已知点高程和 GPS 网点大地高 3 种误差的影响。

关键词: GPS; 水准点; 高程拟合; 大地高; 正常高; 拟合精度。

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利用 GPS 定位技术进行控制测量, 在平面控制测量中, 具有精度高、速度快、费用低等优点, 现已成为建立平面控制测量的重要手段, 但在进行高程控制时其精度相对不足。GPS 高程测量的难点在于确定其高程异常, 大部分是 20 世纪 50 年代由三角高程测量求得, 精度较低。随着 GPS 技术及数据处理软件的不断完善, 利用高程拟合的方法, GPS 定位也将逐步成为高程控制测量的一种方法。在高程控制测量中, GPS 高程控制网是否存在系统误差? GPS 高程控制网在什么情况下能代替四等水准控制测量, 本人通过工作实践, 将体会总结出来与测绘同仁共同探讨。

## 1 GPS 高程测量

$$\delta = H_{\text{大地高}} - H_{\text{正常高}}$$

式中,  $\delta$  为高程异常, 表示似大地水准面至参考椭球面的距离 (如图 1 所示)。

在进行 GPS 测量后, 由 GPS 三维、二维约束平差可得到各点的大地高, 若网中有部分 GPS 点是水准点 (高程控制点) 的联测点, 则这些点的正常高是已知的, 即可求得这些点的高程异常。

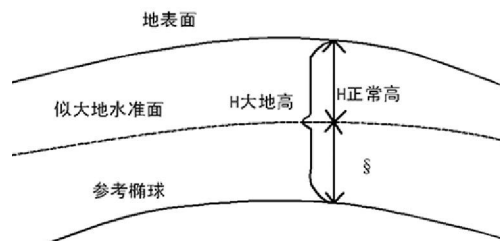


图 1 大地高与正常高的关系图

在一定范围内高程异常不为常数, 但可以认为在此范围内变化平缓, 可用一数学函数来拟合, 求得能反映 GPS 网控制范围中高程异常变化的函数, 然后通过内插求得网中其他各类的高程异常。可见, 研究 GPS 高程的意义是: 精确求得部分 GPS 点的正常高;

求得高精度的似大地水准面。所以, 通常又称利用 GPS 和水准测量成果确定似大地水准面的方法为 GPS 水准。目前, 国内外常用于 GPS 水准计算的方法有: 绘等值线图法、解析内插法 (包括曲线内插法、样条函数法等)、曲面拟合法 (包括平面拟合法、多项式曲面拟合法、非参数回归曲面拟合法和移动曲面法等)。

## 2 几种常用的拟合法

### 2.1 均值挂靠拟合法

该方法的实质是利用在高程异常值变化缓慢的小测区内, 各点的高程异常值相差不大的特点, 用 2-3 个点的高程异常值的平均值代替测区内的各点高程异常值。因此, 其计算精度不很高。该方法的使用条件很有限, 只能在不大于 50 km<sup>2</sup> 的平原或浅丘地区才能使用。如果有条件使用其他计算方法时, 建议不使用此方法计算。

### 2.2 加权平均值拟合法

因为高程异常值是连续渐变的, 所以内插点的高程异常值与该点和周围的水准重合点的距离具有强相关性, 该方法正是根据这一特性产生的。

采用该方法推算未知点的高程异常进行 GPS 高程转换时, 必须使水准重合点沿控制网外围比较均匀地分布, 使推算点位于已知点所围成的多边形内, 否则内插点上计算结果的可靠性不能得到保证。另外, 还应使多边形范围内有一定数量的水准重合点, 并尽可能地均匀分布。控制网中水准重合点的数量越多, 密度越大, 分布情况越好, 该方法求得的高程异常值的准确度就会越高, 即 GPS 大地高转换为正常高的实际精度越高。一般要求一个大的 GPS 网中水准重合点的数量要维持在 10 个左右, 至少为 6 个。

### 2.3 三次样条曲线拟合

当测线长, 已知点多, 高程异常变化大时, 如果

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进行整体拟合精度较低；若分段拟合计算，则分段点上将不连续，且影响拟合精度时，宜采用三次样条曲线拟合。

### 2.4 曲面拟合法

当 GPS 点布设成一定区域面时，可以应用数学曲面拟合法求得待定点的正常高。其方法是：根据测区中已知点的平面坐标 X、Y (或大地坐标 B、L)，用数值拟合法拟合出测区似大地水准面，从而求出待求点的正常高。能否较准确地拟合出该测区的局部似大地水准面的关键取决于已知高程异常的准确性。如果选择的拟合模型较差，势必导致拟合的似大地水准失真，从而影响精度；为了能够实现大地高向正常高的转换，往往在测区内采用联测水准点，但也不能完全避免存在系统误差。因此，GPS 水准高程拟合的精度主要受 GPS 网点的大地高、已知点高程和拟合的似大地水准面 3 种误差的影响。

## 3 测绘工作实践与检验

### 3.1 茂名市城区 GPS 高程测量

茂名市城区一级 GPS 控制网由 174 个一级点和 4 个 GPS-C 级起算点组成，用 4 台徕卡 1200 型双频 GPS 接收机按静态作业模式实施野外观测；基线采用随机商用软件 LGO 进行解算 (如图 2 所示)。全网共取 549 条经 LGO 解算合格的基线参与平差，三维无约束平差采用 PowerAdj 4.0 进行，二维约束平差、高程拟合采用 PowerAdj 4.0 进行。

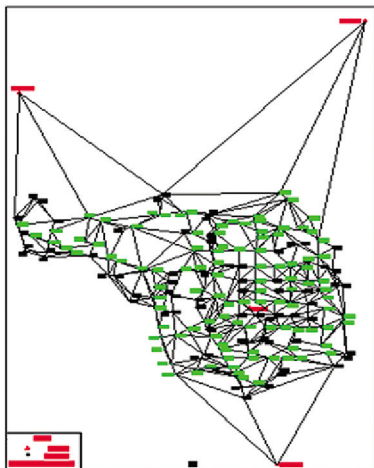


图 2 茂名市城区一级 GPS 控制网图

本控制网采用 48 个经一等水准联测的一级点高程作为全网高程起算，4 个经二等水准联测的一级点高程作为外部检核点 (检核结果见表 1)，水准联测率为 17%，用曲面拟合法求出其余控制点的高程，拟合结果精度良好。具体精度指标如下：

### 符合精度评定

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(第一部分) T 检验

$$t(102) = 0.000$$

(第二部分) 内符合精度：

$$ct_0 = 0.109E+01 \text{ (cm)}$$

(第三部分) 外符合精度：

$$\text{中误差 (+/-, m)} = 0.033$$

外部检核点检验模型的误差如表 1 所示。

表 1 外部检核点检验模型的误差/m

检验点 点号	检验点的 正常高	计算所得 正常高	误差
I032	13.729	13.763	0.034
I021	16.379	16.409	0.030
I102	16.115	16.152	0.037
I115	16.61	16.639	0.029

### 3.2 拟合点高程检测的结果与分析

我们利用二等水准联测方法对茂名市城区一级 GPS 控制网高程成果进行了检测 (如图 3 所示)。采用国家一等水准及三等水准路线 (即 I 廉穗线及 III 茂沙线) 水准点作为高程起点，用四等水准网进行联测，按照《国家三、四等水准测量规范》(GB12898-91) 的有关要求执行，共了联测 102 个 GPS 拟合高程点。四等水准网平差计算采用清华山维 NASEW95 平差软件，以测段距离定权，用纯迭代平差法进行平差计算，闭合差最大的为 013 经 166... 033 至 013 闭合环，闭合差为 0.028 5 m，限差为 0.059 0 m。闭合差最小的为 130 经 110... 147 至 130 闭合环，闭合差为 0.002 0 m，限差为 0.064 1 m。检测结果为 I160 控制点水准实测的高程和 GPS 网拟合解算的高程相差最大值为 ± 0.086 m，部分比较结果见表 2。

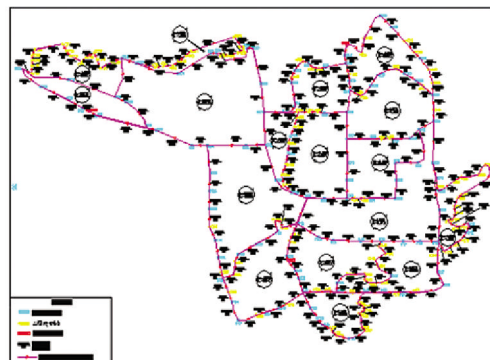


图 3 茂名市二等水准联测网图

从表 2 可以看出：水准高程与 GPS 拟合高程互差均小于 10 cm，若把 GPS 拟合高程当作理论值，则水准高程中误差  $m_0=3.9 \text{ cm}$ ，说明 GPS 高程测量在精度上完全满足《城市测量规范》(CJJ8-99) 要求，而且误差

分布均匀,不存在误差积累。在地形复杂的测区,适当增加水准重合点观测。采用的已知水准点越多,拟

表 2 部分比较结果/m

点名	H <sub>GPS</sub>	H <sub>水准</sub>	H
005	17.616	17.666	-0.050
010	19.807	19.856	-0.049
017	19.996	19.921	0.075
022	24.893	24.895	-0.002
027	20.752	20.763	-0.011
033	13.853	13.849	0.004
040	24.278	24.261	0.017
046	14.426	14.411	0.015
052	30.477	30.413	0.064
058	16.335	16.323	0.012
059	20.314	20.336	-0.022
065	15.922	15.957	-0.035
066	12.817	12.881	-0.064
074	12.656	12.621	0.035
090	30.793	30.752	0.041
097	16.115	16.121	-0.006
105	16.414	16.435	-0.021
119	26.350	26.380	-0.030
131	21.589	21.566	0.023
137	23.378	23.336	0.042
138	17.955	17.925	0.030
146	24.233	24.266	-0.033
147	22.186	22.138	0.048
148	16.167	16.189	-0.022

合精度就越高。从茂名市城区 GPS 拟合点高程检测结果可得出结论, GPS 高程测量代替传统四等水准测量是完全可行的。

## 4 结 语

1) 联测水准点成果质量的好坏直接影响到 GPS 高程的精度。因此在布设联测水准点时应尽量均匀分布,并适当增加水准重合点观测。采用的已知水准点越多,拟合精度就越高。这样,既保证了 GPS 高程控制精度,又提高了工作效率。

2) 观测过程中存在粗差,必须选择有利观测时段,重新观测从而剔除粗差。

3) 有些观测条件很差的地方(如市中心),四周都是高楼大厦, GPS 信号比较差,很难发挥作用。

本文是本人在实际工作中总结出来的一些经验,还需要更多实践去检验,但随着 GPS 技术的高速发展,提高似大地水准面的精度和分辨率,提高平差模型严密性和科学性, GPS 高程代替常规水准测量,将不是一个梦想,而是完全可能的。

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作者简介:丁德生,工程师,主要从事测绘工作。

## 下期论文导读

冯淦 何政伟 邓磊 等:基于遥感指数的崩滑检测方法

以汶川地震时出现的崩滑为研究对象,以该地区震前/后 TM 影像为研究数据,利用变化检测的方法,比较和分析了归一化植被指数(NDVI)、归一化建筑指数(NDBI)和归一化燃烧率(NBR)应用在崩滑检测中的可行性和优劣性。结果表明,3种遥感指数均可以用于崩滑检测,但效果不同:NDVI 对崩滑检测最全面但可信度最低,NBR 对崩滑检测最可信但遗漏最多,NDBI 处于中间水平。

water irrigation area was basically consistent, but the vegetation index in sewage irrigation area showed decreasing trend year by year; in domestic sewage irrigation area, the vegetation showed precocious phenomenon and the vegetation index was the lowest of all the study areas in industrial wastewater irrigation area.

Key words sewage irrigation area , NDVI , dynamic monitoring  
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Data Organization and Classification of "Mineral Management with One-Chart" System by YANG Wensen

Abstract The paper introduced the elementary conception of data center and data structure of "Mineral Management with One-Chart" system, and then described data logic structure and data classification of "Mineral Management with One-Chart" system in detail.

Key words Mineral Management with One-Chart, data organization, mineral rights checking  
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Application of Decision Tree Method in Remote Sensing Information Extraction by CHEN Ye

Abstract Firstly, classifier structure of decision tree and its theoretical basis was introduced. Secondly, classification was carried out for land-use types with the characteristics of remote sensing image in each band. Then, as a case study, the classification experiment was conducted over the area of Yubei in Chongqing. The specific process of implementing classification was demonstrated, and the results showed that the method was practical and feasible to make the classification of remote sensing image based on some training samples of interested area.

Key words decision tree, quadtree and binary tree, ID3, C4.5 and CART algorithm theory, stratified information extraction  
( Page:67 )

Application of GIS and Fractal Theory in Land Use Structure by MI Changlin

Abstract This article took the Liguan town Linyi city as an example to discuss the fractal characteristics of the land use structure. Fractal dimension was discussed to show the relationship between land use and its complexity or stability. From the research, the land use structure of Liguan Town possesses fractal characteristics. Human influence on rural roads, ditches and woodland was outstanding. This three types of land use structure present its complication and irregularity. We should bring out a scientific planning in the future, and especially to plan the rural road, ditches and woodland. It helped to provide scientific decisions in the land use planning.

Key words GIS , fractal theory , land use structure  
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Fitting on the Elevation Accuracy of GPS in Maoming City by DING Desheng

Abstract GPS control network in the united measurable standards point, based on the use of GPS to achieve the level of elevation of the GPS network to normal earth high conversion, the precision is mainly affected by the fitting of the geoid, and GPS locations of known elevation points error of the earth or high impact.

Key words GPS , level points , elevation fitting , geodetic height , normal fitting accuracy  
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Research on GIS Application in Mining Subsidence Area Ecological Value Evaluation by DING Yao

Abstract In this paper, we discussed the use of GIS technology and the principle of multi-source information on complex ecological elements of the planning area and the ecological value of single factor assessment evaluation. Ecological Management and Planning of coal mining subsidence on the evaluation of the ecological value of planning area in Huainan, as this model, we selected the evaluation fac-

tors, including topography, ecological matrix factors, vegetation and water environmental protection factor. Using the combination technologies of Remote Sensing and Geographic Information System to establish the base data platform based on GIS, analyzed and evaluated the ecological value of the planning area using GIS spatial analysis function. By evaluating various ecological factors in planning area, and thorough understanding the characteristics and spatial distribution of ecological value, we could extract the important ecological nodes in order to provide the basis for finding the potential of ecological construction planning area and the implementation of ecological management and construction.

Key words mining subsidence area , ecological management , GIS , ecological value evaluation  
( Page:76 )

Methods of Multi-resources Geospatial Data Integration for LIDAR Data by FEI Yun

Abstract This paper analyzed the characteristics of LIDAR data and some of the typical multi-resources geospatial data. It discussed under the conditions of maintaining data accuracy to achieve the multi-resources data integration. This paper suggested an effective data structure model - the pyramid model, and visible region of the display technology, in order to achieve the integration of multi-source data and fast browsing.

Key words multi-resources data , image fusion , LIDAR  
( Page:79 )

MapGIS Application in Land Boundary Survey by LAI Yonghua

Abstract Combined with working practice , this paper discussed the method of land classification and area statistics in Land Boundary Survey based on MapGIS software.

Key words MapGIS , land classification and area statistics , land boundary survey  
( Page:82 )

Design and Implementation of the 3D Virtual Campus System by HONG Defa

Abstract Virtual reality technology is an emerging technology and widely used in many fields. Virtual campus system as the application of virtual reality technology in the education breaks the limits of space and time. It unfolds the 3D campus scene authentically and vividly. So, many universities have constructed their own virtual campus systems which had different functions. This paper described the functional requirements of virtual campus system and introduced the technology which constructed the virtual campus system. Took the scene of Jilin University and Chaoyang district as the data, the prototype system which had the function of data entry, querying, roaming, space measurement, data updating, the interactive of two and three-dimensional, animation outputting was developed and obtained the satisfactory results.

Key words virtual reality, virtual campus, 3D modeling  
( Page:84 )

Design and Development of MapGIS with Hydrological Information System by LI Deyong

Abstract This paper focused on the current lack of hydrological information management, based on MapGIS platform, using C/S and B/S mixed-mode, combined with GIS, database and computer network technology, using C#, JavaScript and other languages on the development of hydrological integrated information service system. The system studied the hydrological related information sharing and service platform, which was the basic and most important part in hydrological development. It provided timely, comprehensive, multi-level, high-quality information services, and assistance decision-making support to hydrological management as well as flood prevention and drought control departments.

Key words GIS , hydrologic information , real-time monitoring , MapGIS assist decision-making  
( Page:88 )