doi:10.3969/j.issn.1672-4623.2020.11.022

基于精密单点定位获取CGCS2000坐标的方法

魏以宽[1]，唐晓霏[1]，吕世充[2]，孙小超[1]，赵　鹏[1]，范志成[2]
（1. 湖北省测绘工程院，湖北 武汉 430074；2. 湖北省地理国情监测中心，湖北 武汉 430071）

摘　要：精密单点定位技术的精度和可靠性逐渐得到越来越多用户的认可，但通过其直接获得的定位结果与我国的 CGCS2000 坐标系不一致。给出了一种基于基准站网直接将精密单点定位成果转换至 CGCS2000 坐标系的方法。该方法直接利用布尔莎法确定一段时间内 ITRF 参考框架至 CGCS2000 坐标系的转换七参数，并定期更新。实验结果表明，该方法获得的 CGCS2000 坐标误差较小，验证了其可行性。

关键词：精密单点定位；ITRF；坐标转换；CGCS2000
中图分类号：P228.1　　**文献标志码**：B　　**文章编号**：1672-4623（2020）11-0077-03

精密单点定位（PPP）技术是指基于单台接收机，通过载波相位和码伪距的方式，采用精密星历、高精度卫星轨道和钟差产品，利用一些误差改正模型或参数估计的方法，精细考虑与卫星端、信号传播路径以及接收机端有关的误差对定位的影响，实现高精度定位的一种方法。目前，该技术被广泛应用于测量、导航、授时等高精度应用领域，其精度和可靠性逐渐得到越来越多用户的认可[1-4]。

国际地球参考框架（ITRF）是目前国际上公认的精度最高、稳定性最好的参考框架。根据所使用的精密星历文件，PPP 技术直接输出的坐标成果多为 ITRF 最新框架（一般为 ITRF2014）和当前历元[5]。2008 年 7 月 1 日起正式启用的 CGCS2000 国家大地坐标系，由 2000 国家 GPS 大地网的点坐标和速度场具体实现，与 ITRF97 框架一致，参考历元为 2000.0[6]；而工程测量、施工控制测量等情景下多采用确定的坐标系，主要是 CGCS2000 坐标系。

由于板块运动，不同时期同一参考站的位置发生了变化，且不同参考框架下参考站的位置也不一样，因此在处理不同时期不同参考框架的数据时，应进行框架转换和历元转换[7]。CGCS2000 坐标系采用 ITRF97 框架 2000 历元，根据最新的 ITRF2014 框架转换参数，ITRF2014 框架与 ITRF97 框架的变化较小；但由于地球速度场的原因，平面方向随历元的变化每年有 2～3 cm 的变化，2000 历元至 2019 历元累计变化量已超过 50 cm，导致 PPP 成果在工程测量和施工作业中无法直接使用。本文给出了一种基于基准站网直接将 PPP 成果转换至 CGCS2000 坐标系的方法。

1　框架转换方法

目前，ITRF 框架坐标转换方法包括 3 种：①框架、历元统一转换，直接采用布尔莎法求解两个坐标系之间的七参数；②先转换历元后转换框架，即先将两套坐标归算到统一历元，再通过 ITRF 提供的框架转换七参数进行转换；③先转换框架后转换历元，即先通过 ITRF 提供的框架转换七参数将框架统一，再通过速度场变化量计算历元变化。

历元转换的计算公式为[8]：

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\mathrm{ITRF2014}}^{2019} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\mathrm{ITRF2014}}^{2000} + (2019-2000)\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix}_{\mathrm{ITRF2014}}^{2019}$$

框架转换的计算公式为[8]：

$$\begin{cases} T(t) = T(t_k) + \dot{T}(t-t_k) \\ D(t) = D(t_k) + \dot{D}(t-t_k) \\ R(t) = R(t_k) + \dot{R}(t-t_k) \end{cases}$$

式中，T 为平移量；D 为尺度；R 为旋转量；$\dot{T}$、$\dot{D}$、$\dot{R}$ 分别为对应的变化速率；上述参数均可在 ITRF 网站上获取。

由于地球不同板块间的速度场变化方向和速度并不趋同，直接采用布尔莎七参数法会导致较大误差，故在大范围框架下一般不采用第一种方法。然而，本文所应用的地区范围较小，实验区域内的板块运动方向和速率均较稳定，因此直接采用布尔莎法求得 ITRF2014（2019）⟶ITRF97（2000）的转换七参数。

收稿日期：2020-06-28。
项目来源：中国第二代卫星导航系统科技重大专项“湖北省北斗导航应用示范”资助项目（GFZX03030302020203）；精密工程与工业测量国家测绘地理信息局重点实验室开放基金资助项目（PF2011-23）。

2　基于基准站网的框架转换

基准站网能不间断地采集 GNSS 观测数据，可首先利用基准站数据和 IGS 提供的精密星历进行高精度数据处理，获取所有基准站的高精度 ITRF2014 坐标；然后基于所有基准站的 ITRF2014 坐标和 CGCS2000 坐标，直接采用布尔沙模型计算得到两个框架之间的转换七参数；最后将这些参数播发给用户，用户获取 PPP 结果后，可将 ITRF2014 坐标转换为 CGCS2000 坐标。基于基准站网的框架转换流程如图 1 所示。由于 ITRF2014 是动态框架，其瞬时坐标不断变化，在我国范围内运动速度约为 2～3 cm/a，因此本文建议该转换参数每 0.5a 更新一次，从而保证转换参数的现势性。

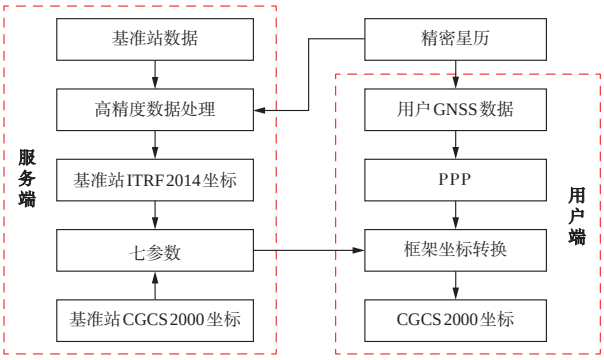

图 1　基于基准站网的框架转换流程图

3　实验设计与结果分析

3.1　实验设计

本文首先选取实验区域内均匀布设的 7 个基准站点进行长期观测，覆盖面积约为 5 000 km^2。基准站数据观测情况说明如表 1 所示，站点分布如图 2 所示。

表 1　基准站数据观测情况说明

编号	观测时间	观测时长	采样率/s	接收机类型
A	2019/5/1	23:59:45	15	Trimble NetR9
B	2019/5/1	23:59:45	15	Trimble NetR9
C	2019/5/1	23:59:45	15	Trimble NetR9
D	2019/5/1	23:59:45	15	Trimble NetR9
E	2019/5/1	23:59:45	15	Trimble NetR9
F	2019/5/1	23:59:45	15	Trimble NetR9
G	2019/5/1	23:59:45	15	Trimble NetR9

本文采用的 PPP 软件为 CSRS-PPP 2.26.1，是由加拿大国家资源部提供的免费在线 PPP 服务。软件基本原理为非差 PPP，服务方式为注册后上传观测文件，解算模式分为静态和动态，可输出 NAD83 框架自选历元或 ITRF 框架当前历元的坐标成果。

本文首先利用 B 点至 G 点的数据进行 PPP，获得这些点的 ITRF2014 坐标；再利用这些点的 ITRF2014 坐标和 CGCS2000 坐标计算坐标转换七参数。将 A 点作为测试点，先利用 PPP 技术获取其 ITRF2014 坐标，再利用获得的七参数将其转换为 CGCS2000 坐标，然后与已知的 CGCS2000 坐标进行比较，从而验证该方法的有效性。

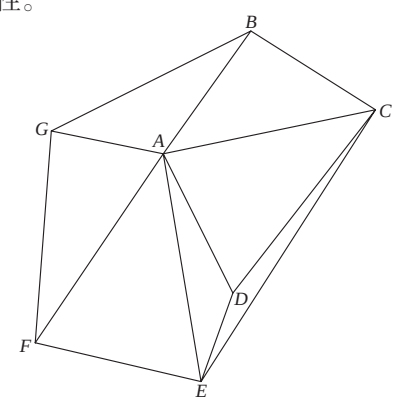

图 2　基准站点位分布图

3.2　坐标转换七参数计算

实验利用 B 点至 G 点的数据获得其 PPP 的 ITRF2014 坐标，并利用该结果与已有的 CGCS2000 坐标计算得到坐标转换七参数。本文以这些点坐标的转换残差作为衡量坐标转换七参数的内符合精度，转换残差如表 2 所示。

表 2　七参数计算兼容性统计/m

点号	源坐标 B/x 转换残差	源坐标 L/y 转换残差	源坐标 H/h 转换残差
B	−0.003	0	0
C	−0.005	−0.006	0.001
D	0.018	0.002	0.010
E	−0.002	0.002	0.002
F	−0.001	0	−0.009
G	−0.005	0.002	−0.003

由表 2 可知，除 D 点最大残差达到 1.8 cm 外，其他点位误差均为 mm 级，兼容性良好，说明坐标转换七参数在该区域使用时具有较高的转换精度。

3.3　PPP 转换成果

以 A 点点位报告为例，X、Y、Z 三个方向的收敛情况如图 3 所示，可以看出，在第 200 个历元处（50 min）平面精度可收敛达到 cm 级精度；在第 477 个历元处（119 min）高程精度可收敛达到 cm 级精度。A 点收敛完成后 95% 置信区间内的中误差分别为 $X=0.002$ m、$Y=0.004$ m、$Z=0.007$ m。

利用获得的坐标转换七参数，将 A 点 PPP 成果转换为 CGCS2000 坐标；再将 CGCS2000 坐标与已知的 CGCS2000 坐标进行比较，X 方向的差值为 0 m，Y 方向的差值为 −0.004 8 m，Z 方向的差值为 −0.002 8 m，可以看出，A 点 X、Y、Z 三个方向的误差均在 mm 级，说明在该范围尺度下，直接使用布尔沙法求解七参数进行坐标转换误差较小。

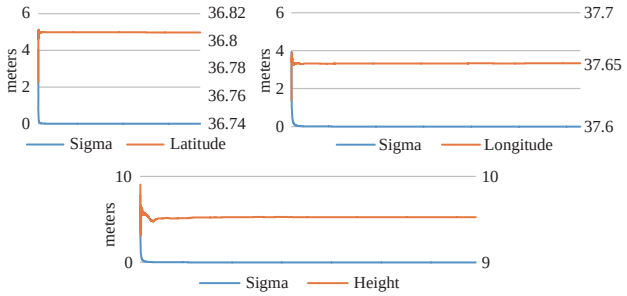

图 3　A 点收敛情况统计图

为了进一步验证该方法的可行性，本文收集 A 点 2019 年 1—6 月每月第一天的 24 h GNSS 观测数据进行 PPP 解算，再将其结果转换至 CGCS2000 坐标，残差如表 3 所示。

表 3　A 点 PPP 结果与已知坐标的差值

年积日	*X* 方向月变化量	*Y* 方向月变化量	*Z* 方向月变化量
001	0.000 0	−0.004 8	−0.002 8
032	0.005 8	−0.006 5	−0.003 7
060	0.003 3	0.000 4	0.003 7
091	0.002 8	−0.001 1	−0.002 3
121	0.004 7	−0.005 3	−0.004 3
152	0.006 5	0.003 7	0.002 6

由表 3 可知，所有结果均小于 1 cm，表明框架转换带来的误差有限，不会影响 cm 级别的测绘工程应用，同时证明了本文方法的有效性。值得注意的是，在 ITRF2014 框架下，基准站瞬时坐标不断变化，转换参数需要定期更新才能保证转换参数的现势性。

4　结　语

一般测绘 RTK 作业中可能会发生网络信号不稳定、CORS 服务故障等突发状况，可考虑先采用静态观测模式布设控制点，再将静态数据进行 PPP 处理，最后通过框架转换获得所需坐标成果的方式。由于 PPP 的非差特性，无需架设多台设备组网进行同步观测，大大减轻了作业负担，提高了工作效率。本文给出了一种基于基准站网直接将 PPP 成果转换为 CGCS2000 坐标的方法。该方法直接采用布尔莎法确定了一定时间内 ITRF 参考框架至 CGCS2000 参考框架的转换七参数。实验结果表明，该方法获得的 CGCS2000 坐标成果误差较小，验证了该方法的可行性。

由于地球速度场的变化速率较低，因此以 30 d 左右的频率更新区域转换参数，可达到全自动在线静态数据处理的目的。由于其解算过程中没有组网平差，各点之间无法做到互相检校，因此在其计算过程中尽可能多地加入已知坐标点，并需对已知坐标点进行兼容性检查，剔除兼容性较差的起算点或利用组网平差软件对观测基线长度进行复核，以保证 PPP 技术处理的可靠性。

参考文献

[1] 张小红, 李星星, 郭斐, 等.GPS 单频精密单点定位软件实现与精度分析[J]. 武汉大学学报(信息科学版),2008,33(8):783-787
[2] 郭斐. GPS 精密单点定位质量控制与分析的相关理论和方法研究[D]. 武汉: 武汉大学,2013
[3] 刘明亮, 丁克良, 刘亚杰, 等. BDS 精密单点定位在桥梁变形监测中的应用[J]. 全球定位系统,2019,44(2):98-102
[4] 林晓静, 张小红, 郭斐, 等. 影响精密单点定位收敛速度的因素分析[J]. 测绘信息与工程,2010,35(3):10-12
[5] 陈俊勇. 大地坐标框架理论和实践的进展[J]. 大地测量与地球动力学,2007,27(1):1-6
[6] 于强, 易长荣, 占惠. ITRF2000 转换到CGCS2000 框架的分析[J]. 全球定位系统,2009,34(5):49-51
[7] 刘立, 成英燕. ITRF 框架的相互转化[J]. 大地测量与地球动力学,2010,30(2):141-143
[8] 尹伟言, 赵鑫. ITRF 框架坐标转换问题的研究[J]. 测绘技术装备,2012,14(3):3-6

第一作者简介：魏以宽，主要从事 GNSS 导航定位等研究和 CORS 系统运行维护工作。

（上接第 76 页）

[5] 李敏, 沈正平. 城市地名普查工作的主要经验及建议[J]. 中国地名,2010(7):21-23
[6] 龚元夫, 高建洲, 陈关州, 等. 湖北省第二次全国地名普查关键技术研究[J]. 中国地名,2017(3):12-15
[7] 万玛宁, 关永, 韩相军. 嵌入式数据库典型技术 SQLite 和 Berkeley DB 的研究[J]. 微计算机信息,2006(2):91-93
[8] 聂上森. 基于ArcGIS Runtime SDK的外业数据采集系统设计与实现[D]. 成都: 西南交通大学,2015
[9] 傅筱白, 龚元夫, 高建洲, 等. 地名普查大数据应用与公共服务融合研究[J]. 中国地名,2018(4):14-17
[10] 黄燕平. 基于移动GIS的城市井盖信息采集系统设计与实现[J]. 测绘与空间地理信息,2019,42(10):134-137
[11] 国务院第二次全国地名普查领导小组办公室.第二次全国地名普查数据建库与管理软件设计规范[R].

第一作者简介：陶彣君，工程硕士，高级工程师，主要从事测绘技术管理工作。

Real Scene 3D Modeling of Airborne and Ground Images Based on Dp-Modeler Platform by *DI Guohui*
Abstract Deformation, deletion and other issues often appear in the near ground part of the real scene 3D model based oblique photogrammetry technology. However, using ground image to help oblique photographic images can make the 3D model finer and more complete. Based on Dp-Modeler platform, we used aerial triangulation with auxiliary GPS to solve the attitude determination problem of the ground images when they combined with aerial photographs, which could realize the coupling relationship between oblique photographic images and ground images.
Key words real scene 3D model, oblique photogrammetry, ground image, attitude determination (Page: 48)

Application of True 3D Model Based on Laser Point Cloud in GIS by *LIAO Zhongping*
Abstract Aiming at the defects of poor accuracy and low simulation of traditional 3D modeling, we proposed a set of technical solution to embed true 3D model in GIS. Firstly, we used 3D laser scanning system to obtain the point cloud data on the surface of buildings. Secondly, we used Cyclone software to proceed point cloud preprocessing and 3D modeling. Thirdly, we used Google SketcheUp to convert the 3D model texture map and model data format. And then, we cited ArcGIS Engine into the Visual Studio ($C^{\#}$) project to retrieve the model. Finally, we realized the visualization of the true 3D model, model information query and voice broadcast and other functions, which could provide a set of feasible technical solutions for the establishment of true 3D GIS data service system.
Key words Cyclone software, point cloud, 3D model, 3D GIS, voice broadcast (Page: 51)

Research on Changxing Reservoir Immigrant Information Management System Based on GIS Technology by *LI Yabin*
Abstract Based on GIS technology, taking Changxing water conservancy project for example, we developed a Changxing reservoir immigrant information management system in this paper. This system can realize the immigrant basic data management, the construction project management, 3D simulation technology and dynamic tracking management, and comparative analyzed before and after the construction of the project. The system can be well applied into the specific water conservancy project planning and construction, which can make the planning, management and decision-making of immigrant work more efficient, and realize the scientificity and availability of water conservancy project immigrant work
Key words GIS, immigration, Changxing reservoir (Page: 54)

Spatial Quantification and Evaluation of Water Resource in Fu River Basin Based on AHP Method by *HUANG Cheng*
Abstract The spatial balance of water resource is one of the concepts of water management in the new period, and it is of great significance to the harmonious development of water resource and economic society. Aiming at the current situation of water resource shortage in Fu River basin and uneven spatio-temporal rainfall, we established a water resource spatial quantification and evaluation model for watersheds. In this model, we selected 4 factors including average annual rainfall, terrain slope, basin catchment area and basin GDP as the influence factors, used GIS spatial analysis methods to quantify the influence factors into the spatial grid, and applied AHP to optimize the weights of influence factors, which realized the spatial quantification and evaluation of water resource in the Fu River basin. The overall accuracy of the model was 0.87. The results show that this model has good rationality and accuracy, and can provide a basis for related research, so as to facilitate the reasonable implementation of measures to improve local water conditions.
Key words spatial quantification of water resource, water resource evaluation, AHP, Fu River basin, GIS (Page: 56)

Design and Implementation of Geological Data Query System Based on WMTS by *ZHOU Xin*
Abstract According to the problems in the current geological map query process, such as geological map can not be combined with the regional map, geological maps take up too much memory space, query return results need to take time to filter, we designed and implemented a geological data query system based on B/S architecture, which combined with the WMTS, WebGIS, AJAX, Echarts technology. This system is convenient for geological workers to carry out exist geological data query and analysis, and can improve the use efficiency of geological map.
Key words geological map, WMTS, WebGIS, query system (Page: 60)

Research and Implementation of Image Optimizing and Automatic Production of Standard Map by *WANG Ning*
Abstract In view of the inefficiency of satellite image data screening and image production, we designed a simple and feasible method for image data screening, which could quickly screen high quality image data covering once in the work area according to the information of region scope and image attributes. At the same time, according to the process standards of image production procedures, based on Model Builder, combining with the tools provided by ArcToolBox, we implemented an image automatic production method. The application of this method in practical project shows that this method can greatly improve the efficiency of image screening and production.
Key words Model Builder, image product, image optimizing (Page: 63)

Spatial Analysis of Wuhua County Tourism Development Based on GIS Technology by *CHEN Yankui*
Abstract In this paper, we used Python Web crawler technology to obtain the spatial information of 244 tourism resource points in Wuhua County, and used the GIS spatial nuclear density method, the shortest distance analysis method and map mapping technology to analyze the development status and existing problems of Wuhua County tourism resources. Taking the revitalization strategy and the favorable policies of the Central Soviet Area as an opportunity, according to the guidance of the government and the participation of the whole people, we promoted the regional cooperation and differentiated development ideas of tourism resources products, and proposed the spatial framework for tourism development of "four regiments and three lines". According to the characteristics of tourism resources in Wuhua County, we divided it into four characteristic tourism areas, such as the northern mud spring cultural tourism area, the western landscape agriculture and forestry leisure tourism area, the central football characteristic town tourism area, and the southeast custom red tourism area. We designed three tourism development paths, such as "Huacheng-Shuizhai-Hedong-Guotian" tourism traffic line, "Shuizhai-Hengpo-Anliu-Meilin" tourism traffic line, "Shuangtou-Tanxia-Changbu" tourism traffic line.
Key words rural revitalization, tourism, GIS technology, development path, Wuhua County (Page: 66)

Application of UVA Oblique Photogrammetry in Tennis Education by *ZHANG Bo*
Abstract In this article, we mainly introduced the process of real scene 3D model reconstruction using by UAV oblique photogrammetry system, and analyzed the key technologies. Then, we used the DJI M300 RTK UAV to carry out 3D model reconstruction, intelligent tracking, automatic acquisition of motion trajectories in the field of tennis education.
Key words oblique photogrammetry, data fusion, tennis education (Page: 71)

Design of Toponym Information Collection System Based on GIS Technology by *TAO Wenjun*
Abstract In this paper, we designed and implemented a toponym information collection system including PC and mobile client at first. And then, we briefly introduced the design idea, the overall system structure and the database structure of the system, and the collection business process based on this system. The system can simplify the collection process of toponym information, improve the efficiency of the collection, realize the digitization and informatization of toponym data, and greatly improve the value of toponym data.
Key words toponym information, toponym information collection system, toponym database, general database, subdatabase (Page: 74)

Research on Acquisition Method of CGCS2000 Coordinate Based on Precise Point Positioning by *WEI Yikuan*
Abstract The precision and reliability of precise point positioning technology are gradually recognized by more and more users, but the direct positioning results obtained by it are not consistent with the CGCS2000 coordinate system in China. In this paper, we introduced a method based on seven-parameter conversion to directly convert the precision point positioning results to the CGCS2000 coordinate system in a small area. By directly adopting the Bursa method to obtain the transformation seven parameters of different reference frames in different periods, the calculation results after coordinate transformation had less error, which verified the feasibility of the method in the test area.
Key words precise point positioning, ITRF, coordinate transformation, CGCS2000 (Page: 77)

Precision Analysis of Large Scale Mapping with UAV in the Yangtze River Channel by *XIONG Rongjun*
Abstract High-precision geometric information is the basic data for the channel rectification, shoreline management and ecological protection in the Yangtze River. Compared with manual ground measurement or satellite measurement methods, unmanned aerial vehicle (UAV) aerial survey technology has the advantages of flexibility, high efficiency and high precision. However, when applying to the Yangtze River channel measurement, the accuracy of existing UAV technology is still unknown. Therefore, we adopted six current mainstream UAV to carry out the experiment in a typical area of the Yangtze River channel. Based on the ground measured data, we analyzed and compared the accuracy of the digital orthophoto map, digital elevation model and the digital line graphic results from UAV. The results show that the plane accuracy of point cloud is 0.08～0.11 m and the elevation accuracy is 0.05～0.11 m. The plane accuracy of stereo photogrammetry is 0.06～0.08 m and the elevation accuracy is 0.03～0.04 m. The accuracy of current UAV aerial survey technology is able to meet the precision requirements of the 1∶500 large scale mapping in the Yangtze River channel.
Key words UAV, aerial survey technology, Yangtze River channel, large scale mapping (Page: 80)

Design and Implementation of Data Quality Inspection Software Based on FME Template File by *MENG Guisheng*
Abstract Although the conventional data quality inspection software having the advantages of high efficiency, automatic processing and uniform inspection standard, there are problems such as limited data formats supported, limited changes in software and low software adaptability. In this paper, we adopted