

The Research on the Coordinate Transformation Method of Wide Area CORS

Guofu Pan and Zhixiong Bao

Abstract A new TIN-based grid interpolation method is proposed for coordinate transformation of wide area CORS. The method works well in case of grid edge interpolation or abnormal distribution of known points. A compatible online transformation system is designed. Experiment proves the coordinate transformation result is accurate and the improved strategy based on TIN is effective.

Keywords CORS · Grid coordinate transformation · Online transformation

1 Introduction

The user must do the coordinate transformation to obtain the local coordinates results in the use of continuously operating reference stations (CORS). Conventional coordinate transformation method of the small area represented by the Burse-Wolf conversion model [1] is difficult to apply due to the wide coverage of the wide area CORS. The main reason is the partition calculation parameters generates a large number of transformation parameters, which cause great inconvenience to the management and maintenance and update of the parameters. At the same time due to the quantity and quality of the regional control points are different, coupled with a lack of standards to select point has led to the boundary region conversion accuracy is not uniform, the results are not consistent.

G. Pan (✉) · Z. Bao
10th Floor, Chuangxin Building, Tian'an Technology Zone,
No 555 YinBin Road, PanYu, Guangzhou City, China
e-mail: blue.pan@163.com

In this paper, we proposed a grid-based coordinate transformation method to solve the problem of the continuity of results. It combines online coordinate conversion system to achieve real-time and confidential conversion.

2 Grid-Based Coordinate Transformation Method

2.1 Outline

The grid-based conversion method is a two-step interpolation method. It has been used in various regions and achieved good conversion precision [2]. Usually, the known discrete point data field will be modeled to fit the geometry surface in the first, then the values are interpolated at the specified grid node location. Scanning the value of each node and stored to a specific format file to create a grid file. Figure 1 shows the conception of grid and node scanning.

The known points difference of two different coordinate system constitute three discrete data points in the plane direction and elevation direction. By selecting the appropriate fitting and interpolation model to create grid parameter file for different transformation between different coordinate system.

2.2 Fitting and Interpolation Model

There are many discrete data fitting and interpolation method [3] include unitary fitting and local fitting methods. Surveying and mapping fields often use local fitting strategy in practice. Usually mobile search methods are applied to find close neighbors, then a different functional models or statistical models is used to interpolate. The mobile search strategies include to select the a fixed number points or all points within the fixed window (rectangular or circular). The fitting models include polynomial regression, inverse distance weighted method, kriging method, minimum curvature method, or statistical model approximation.

Many scholars have studied the pros and cons on the fitting model [4]. But rarely mentioned how to solve the problems of edge point interpolation and abnormal distribution of known points. To be brief, this chapter will focus on typical planar fitting, the weighted quadratic surface fitting, inverse distance weighted method.

The formula of Planar fitting:

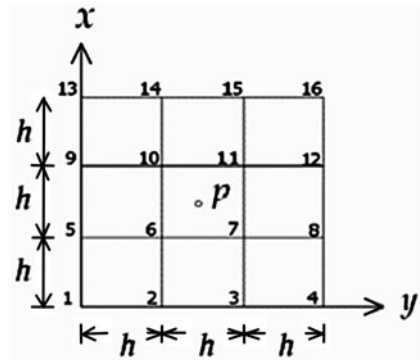
$$U(N, E) = b_0 + b_1 * N + b_2 * E \quad (1)$$

The formula of quadratic surface fitting:

$$U(N, E) = b_0 + b_1 * N + b_2 * E + b_3 * N^2 + b_4 * E^2 + b_5 * N * E \quad (2)$$

where N, E are the north and east coordinate in grid coordinate, b_i represents the quadratic surface model coefficients, U represents the interpolation result.

Fig. 1 Conception of grid and node scanning



Inverse distance weighting method based on the geometric distances between interpolate point and known points to calculate weighted average value in accordance with different strategies. In this chapter we use piecewise function weighted model.

2.3 Edge Points and the Known Points Abnormal Distributed Processing

As the points obtained by the mobile search may be located in a straight line. Such a geometric distribution will lead to obtain the model parameter errors and can not be extrapolated. To avoid this, we may construct an irregular triangular network (TIN) as the secondary search information. In the first step, we will search the nearby triangles to get a set of normal distributed points, then search for the best known points in it. As to the edge point, it is not good for geometric function fitting so we use the Inverse distance weighting method.

Detailed algorithm flow: first step, create TIN and build indexing tree [5] for all triangles and known points. Second step, search for the N nearest triangles and look for abnormal triangles. Third step, if abnormal triangle is not find that means points are normally distributed then equations can be formed by the with the distance weighted result. Coefficients of the models can be determined from (1) or (2) by the least squares adjust method and apply to interpolation. But if abnormal triangle is find that means points are abnormally distributed and the inverse distance weighting method will be applied.

2.4 The Design of the Grid File Format

Interpolate all the node value by from west to east, from south to north order and store in binary format for high-speed addressing data retrieve. Meta data we are attached include start position, increment value, number of columns and rows, interpolation model, invalid identification number and so on.

In calculation the nearby nodes number can be easily calculated by the interpolate position then multiplied by 8 (length of double type) to get the data position in file.

In practice, the grid file will be encrypted before publish.

2.5 Interpolation Based on Grid File

Find the nearest 4 or 16 grid nodes then bilinear interpolation or bicubic spline surface interpolation calculation can be used. Many scholars have studied the pros and cons on the interpolation model [6] and we applied bicubic spline surface model. Here is the node searching method.

As shown in Fig. 1, suppose that interpolate position is P with coordinate (X,Y), and the start position of the grid file is (X0,Y0), both north and east direction increment are h, there are M nodes in x direction and N nodes in y direction. So the nearest four nodes index in grid file can be calculated by the following formula (3):

$$\begin{cases} \text{Node 6} = \text{Int} \left(\frac{Y-Y_0}{h} \right) * M + \text{Int} \left(\frac{X-X_0}{h} \right) \\ \text{Node 7} = \text{Node 6} + 1 \\ \text{Node 10} = \text{Node 6} + M \\ \text{Node 11} = \text{Node 10} + 1 \end{cases} \quad (3)$$

In fact, by using formula (3) we can get other 12 nearby node for bicubic spline surface model.

3 Compatible Online Transformation System

3.1 Overview

Many scholars have studied the pros and cons on the online coordinate transformation system [7]. The main purpose is to prevent users from access to classified data. So that the calculation must be done in the service center. Field workers only have to send the source results to service center in real time by GPRS network and get the converted local results. Currently most instrument manufacturer provide the filed book with GPRS model. At the same time the GPRS networks are widely established in China, so online transformation is technically feasible.

The existing online coordinate conversion system is developed by the national department. It is a closed system because it is designed for private use only. But for wide area CORS, it must consider the different field book software developed by different company. This chapter focus on the compatibility of software and cross language develop problem. A reasonable design, including communication protocols and interfaces to ensure the software of different company can easily access the system. At the same time to ensure data safety and robustness of the server software.

3.2 User Operating Mode Design

As usually there are kinds of local coordinate system in a region. In order to serve different users we have designed user operation mode like this:

Step 1. The user access to system with a user name and password to login and get the available coordinate transformation name table and index ID.

Step 2. The user choose the target system by name then apply the index ID to all the data packet while online transformation.

3.3 Filed Book Software Compatibility Design

The key of a success online conversion system is whether the different instrument manufacturers field book software can easily access to system. From the perspective of program development. Online system should be compatible with various software, that involves OS platform and program language problem (Windows Mobile, Windows CE, Android, iOS and EVC, C#, Java, EVB, etc.).

This chapter designed the system to use TCP/IP communications as a way of exchanging data of the manufacturers hand book software and service software. By creating a set of communication protocols and data formats and open to all the manufactures.

Meanwhile, in order to further simplify the difficulty of the manufacturers hand book software modifications. This chapter designed a client service software as a transit interface. Field book software is actually exchange data with this interface software in the same machine and the interface software communicate with service software which is located in remote control center. This design ensures the independence of the manufacturers hand book software and also very easy to maintain and later extent. This design is shown in Fig. 2.

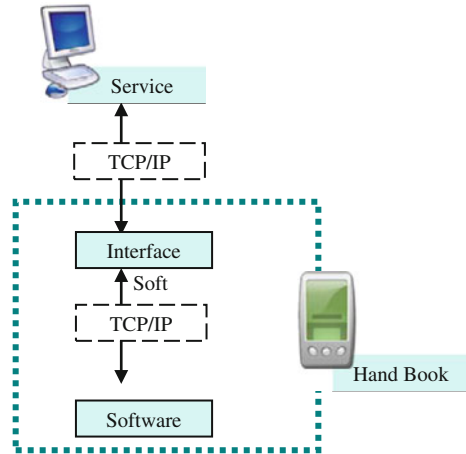
As shown in Fig. 2 interface software plays the role of transit software, actually, interface software has log in, online test, dropped automatically re-login feature. Hand book software only need to activate interface software and log in using the interface software as a coordinate transformation function. Interface software and hand book software are both running in the same machine, TCP/IP communication is very stable, thus ensuring the stability of the hand book software.

3.4 Data Security Measures

Service software involves a lot of confidential data so the security measures of the parameter files and grid data files are very important.

- (1) All the parameters are encrypted by administrator before publish.
- (2) Encrypted parameter files will be deleted after loading to memory.

Fig. 2 Components of end user software



- (3) Limit the convert frequency of online users to avoid malicious users to high-frequency conversion and mass conversion of the large area.
- (4) Group the users. The user can work only in the authorized area.
- (5) User behavior logs all records to the database, in order to query and illegal acts detected.

3.5 Stability Design of the Service Software

Since GPRS network is not stable in some region or some time period, this will result in data communication obstacles or delay or even incorrect data. Measures of stability and availability of services in order to protect the system is a must:

- (1) CRC bytes are included to check the correctness of data packet.
- (2) Packet loss checks and resend rules are included to increase the success rate.

4 Specific Example

4.1 The Accuracy of the Grid Evaluation Model

The application areas in Romania, for example, the region's east-west span of 10° north-south span of 5° , with an area of $240,000 \text{ km}^2$. Randomly resample calculated 2,346 points in the region from the high-precision grid data, the average distance is 13.04 km.

Three dimensional grid files are generated using these points treated as the precision are same. Then calculate the coordinate of these point by using grid files

Table 1 Comparison among different interpolation method in latitude direction

Method	Amount of the differences calculated (m) Max	MSE	AVG
Plane fitting	11.03505	0.23333	0.01927
Quadratic surface fitting	32.71574	0.67743	0.04183
IDW	15.66490	0.31972	0.05160
Comprehensive strategy	0.189390	0.01107	0.00740

Table 2 Comparison among different interpolation method in longitude direction

Method	Amount of the differences calculated (m) Max	MSE	AVG
Plane fitting	16.74534	0.40518	0.02681
Quadratic surface fitting	142.7556	2.90712	0.09350
IDW	68.29594	1.38440	0.07951
Comprehensive strategy	0.16390	0.01073	0.00745

Table 3 Comparison among different interpolation method in altitude direction

Method	Amount of the differences calculated (m) Max	MSE	AVG
Plane fitting	17.49918	0.41863	0.02728
Quadratic surface fitting	1089.67361	22.12422	0.49986
IDW	521.39694	10.56939	0.28681
Comprehensive strategy	0.14666	0.01119	0.00787

such to compare the differences between different modeling method. Indicators include absolute average (AVG), maximum, MSE.

4.2 Analysis

By using different methods mentioned above to generated different grid files in this region. Recalculate the interpolated value of each known points by using bicubic spline surface model. To facilitate the analysis, the differences are converted into meters. Per second corresponds to the arc length in the middle point of the region. One second of latitude corresponds to 30 m, longitude 1 s corresponds to 24 m, the results are as follows.

As can be seen from Tables 1, 2 and 3 that Quadratic surface fitting is not stable. Analysis showed that the gross errors are calculated in the edge region. Plane fitting method is not feasible in this case and may produce gross error too. Proposed method can effectively deal with edge points interpolation and achieve millimeter precision conversion.

Fig. 3 Grid visualization
result in north direction



Fig. 4 Grid visualization
result in east direction

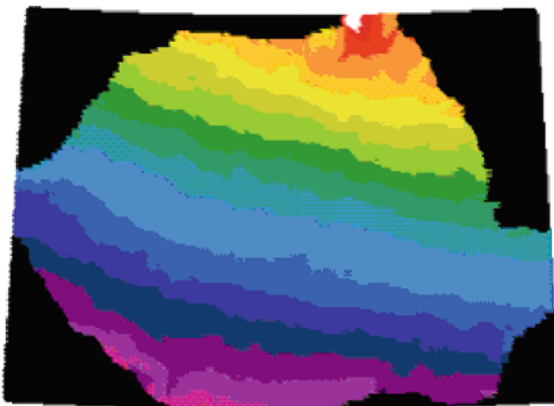
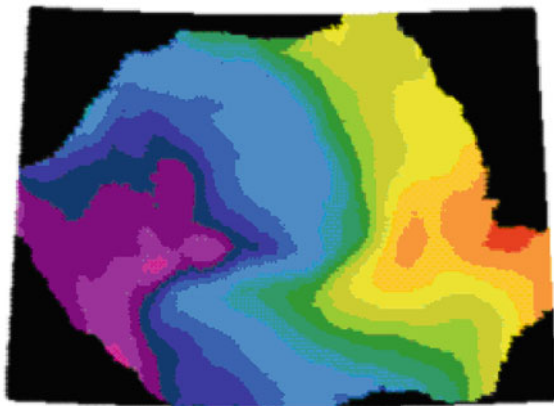


Fig. 5 Grid visualization
result in elevation direction



Figures 3, 4, and 5 show the grid data visualization results of the region in north, East and elevation direction.

From the charts we can see that the interpolation results achieved by comprehensive strategy method have good smooth and continuous features. Data in elevation direction is much more significant and complex than the data in plane direction. Given this feature, it should be considered to apply relatively complex models for the fitting and interpolation in elevation direction.

5 Conclusion

To build wide area CORS system in the future [8], we are facing the encryption coordinate transformation problem and software compatibility problem in practical use. In this paper we proposed the grid-based computing method combined with online coordinate transformation system which provide a fast and high-precision solution. At the same time we proposed a new TIN-based grid interpolation method which is more robust in case of grid edge interpolation or abnormal distribution of know points. Besides, the other functional models or statistical models can also learn from the ideas.

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