Implement of Overhauser magnetometer coordinate transformation software

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Abstract. Two kinds of coordinate projections of Overhauser magnetometer coordinate transformation are studied in this paper. On this basis, the MFC program of Visual C++ is programmed independently. The program implements accurate conversion of Gauss-Krüger projection coordinates and UTM projection coordinates to the WGS-84 geodetic coordinates. It is verified by the examples that both forward projection calculation errors are less than 1.0m. The error of Gauss inverse calculation is less than $10^{-3}$ degrees, while the error of UTM projection coordinate inverse calculation is less than $10^{-5}$ degrees. This research provides assistance for magnetic survey workers to generate coordinate images, and is also the theoretical basis for the corresponding function of magnetometer PC software.

1. Introduction
The GPS module of Overhauser magnetometer is mainly used to generate coordinate images, accurately locate magnetic anomalies, aeromagnetic measurements and other aspects. WGS-84 is a coordinate system established for the use of GPS global positioning system[1,2]. In China, people mainly use the plane coordinate system such as Beijing-54 and Xi’an-80 to obtain map information, while most other countries use the Universal Transverse Mercator projection. Therefore, it is necessary to preprocess and convert GPS coordinate values in different environments.

This paper studies two kinds of coordinate projections of Overhauser magnetometer coordinate transformation. On this basis, the MFC program of Visual C++ is programmed independently. The program implements accurate conversion of Gauss-Krüger projection coordinates and UTM projection coordinates to the WGS-84 geodetic coordinates.

2. Transformation between Gauss-Krüger projection Coordinates and Geodetic Coordinates

2.1Gauss-Krüger projection description
Gauss projection was drawn up by German mathematician Gauss in the 1820s, and was supplemented by German geodesist Krüger in 1912. Therefore, it is called Gauss-Krüger projection, also known as "Equiangular Transverse Elliptic Cylinder Projection"[3]. Its geometric concept is: Suppose there is an elliptic cylinder tangent to a meridian on the earth ellipsoid, the central axis of the elliptic cylinder coincides with the equatorial plane, and the earth ellipsoid is conditionally projected onto the ellipsoid cylindrical surface[1], as shown in Figure 1.
The earth ellipsoid is tangent to the elliptic cylinder, and the axis line of the elliptic cylinder is located on the equatorial plane of the earth ellipsoid. The blue line is a 6-degree zone. $O_E$ represents the true coordinate origin of Gauss-Krüger projection zone[1].

The zoning mode of Gauss projection is divided into 6-degree zones and 3-degree zones. The 6-degree zones is divided from west to east at intervals of 6° from meridian, numbered 1, 2, 3, ...[4]. The longitude of the central meridian in China's 6-degree zones ranges from 69° to 135°, totalling 12 zones (12 to 23 zones). The central meridian of a part of the 3-degree zones coincides with the central meridian of the 6-degree zones, and the other part coincides with the boundary meridian of the 6-degree zones. The number of 3-degree zones in China is 22 (24 to 45 zones)[5]. Their relationship is shown in Figure 2.

![Figure 2. Zone dividing method of Gauss-Krüger Projection](image)

Figure 2. Zone dividing method of Gauss-Krüger Projection

Conditions of Gauss-Krüger projection are as follows [1, 3]:
(1). The central meridian has no length deformation after projection.
(2). After projection, there is no angular deformation.
(3). The central meridian and the equatorial projection line are mutually perpendicular lines, which are the axes of symmetry of other latitude and longitude lines. The farther away from the central meridian, the more obvious the deformation.

According to projection condition (2), Gauss-Krüger projection is a kind of orthographic projection. So it must satisfy the general condition of orthographic projection. In addition, the above (1) and (3) limit the special conditions of Gauss projection itself, thus the transformation of geodetic coordinates to plane coordinates can be completed, and the mathematical formula can be obtained.

### 2.2 An example of Gauss projection calculation program and its correctness verification

Since the specific forward and inverse calculation formulas of Gauss projection are discussed in detail in many documents, such as Deakin, R. E. et al.(2010), Dorrer, E.(2003), Kawase, K.(2011)[1,3,4], it is not described in this paper. The example data used in the experiment are based on Krasovsky ellipsoid parameter, which is the basis for reference of Beijing-54 coordinate system model. The
calculation example data is derived from the “Geodesy Basis”[5]. The accuracy of the calculation program is examined by comparing the original calculation results in the book with the reference value. The calculation results are shown in Table 1 and Table 2.

| Input latitude and longitude value (°) | Gauss X/Y coordinate calculated by JEMLab2.0 (m) | Gauss X/Y coordinate reference value (m) | Error (m) |
|---------------------------------------|-----------------------------------------------|----------------------------------------|-----------|
| B=30°30’                             | x=3380330.773                                 | x=3380330.875                          | x=0.102   |
| L=114°20’                            | y=320089.9696                                 | y=320089.9761                          | y=0.065   |

Table 2. Inverse Calculation Examples of Gauss Projection

| Input Gauss X/Y coordinate (m) | Latitude and longitude results of JEMLab2.0 (°) | Latitude and longitude reference value (°) | Error (°) |
|--------------------------------|-----------------------------------------------|----------------------------------------|-----------|
| x=3380330.875                 | B=30°29’58.82”’                               | B=30°30’                               | B=0°0’01.18 |
| y=320089.9761                 | L=114°19’99.99”’                               | L=114°20’                              | L=0°      |

Through the comparison of the calculation example, the error between the program and reference value is less than 1.0m. The error of Gauss inverse calculation is less than 10^{-3} degrees.

3. Transformation between Universal Transverse Mercator (UTM) Projection Coordinates and Geodetic Coordinates

3.1 Introduction to Universal Transverse Mercator projection

With the popularity of satellite measurements, the U.S. Army Bureau of Engineering Surveying and Mapping proposed the concept of Universal Transverse Mercator projection, referred to as UTM projection. It is a projection system similar to Gauss-Krüger equiangular transverse elliptic cylinder projection, as is shown in Figure 3. The UTM projection zoning method is similar to the Gauss-Krüger projection. The UTM projection partitioning method is similar to the Gauss-Krüger projection. This projection divides the Earth into 60 zones from west to east every 6°[2]. The UTM projection is the mathematical basis for measuring topographic maps in areas from 80° south latitude to 84° north latitude. UTM projection is often used for satellite image data in China.

The earth ellipsoid is bisected by the elliptic cylinder to form two secant circles (i.e. the blue lines N_N -S_N and N_E -S_E ). The circle passing through the central meridian (i.e. the central red line N_P -O_E -S_P , the center of the circle being the center of the earth's core O) is parallel and equal in size to the
two blue secant circles. The axis of the elliptic cylinder passes through the centroid and is located on the equatorial plane. \( R_E \) and \( R_P \) are the equator and polar radius of the earth ellipsoid respectively. \( O_E \) is the true origin of the projected coordinates[2].

3.2 UTM coordinate conversion program flowchart

![Diagram of UTM projection coordinate conversion process](image)

Figure 4. Schematic diagram of UTM projection coordinate conversion process[2]

Since the specific calculation formulas of UTM projection are discussed in detail in many documents, such as Hofmann, B. et al.(2010), Langley, R. B.(1998), Dozier, J.(1980)[2,6,7], it is not described in this paper.
3.3 Calculation results and error comparison
The program selects the GPS coordinates of the three major cities in China. The data calculated by UTM coordinate conversion program of GEMLink5.3 software are used as comparison value to check the accuracy of JEMLab2.0 coordinate calculation program. The results are shown in Table 3.

| City     | Software       | Initial geodetic coordinates | Forward coordinate transformation | Inverse coordinate transformation |
|----------|----------------|------------------------------|-----------------------------------|----------------------------------|
|          |                | Latitude (°) | Longitude(°) | UTM X(m) | UTM Y(m) | Latitude (°) | Longitude(°) |
| Beijing  | JEMLab 2.0     | 39.9061111  | 116.38805555 | 447692.952554  | 695 | 4417515.758241 | 512 | 39.9061111 | 116.3880555 |
|          | GEMLink 5.3    | 39.9061111  | 116.38805555 | 447692.956821  | 788 | 4417515.757368 | 38  | 39.9061111 | 116.3880555 |
|          | Error          | 0.004267    | 0.000873      |          |       |                  |      |          |              |
| Shanghai | JEMLab 2.0     | 31.24805555 | 121.47305555 | 354599.319616 | 213 | 3458098.452297 | 912 | 31.2480555 | 121.4730555 |
|          | GEMLink 5.3    | 31.24805555 | 121.47305555 | 354599.319617 | 7  | 3458098.452527 | 4   | 31.2480555 | 121.4730555 |
|          | Error          | 0.000001    | 0.000230      |          |       |                  |      |          |              |
| Changan  | JEMLab 2.0     | 43.8811111  | 125.31305555 | 685819.128980 | 216 | 4861268.895023 | 901 | 43.8811111 | 125.3130555 |
|          | GEMLink 5.3    | 43.8811111  | 125.31305555 | 685819.128976 | 783 | 4861268.895301 | 27  | 43.8811111 | 125.3130555 |
|          | Error          | 0.000003    | 0.000277      |          |       |                  |      |          |              |

Since the influence of the high power factor term on the result is ignored in actual programming, resulting in slight error, but the accuracy of the programming result is not affected.

4. JEMLab 2.0 software main interface and GPS projection coordinate conversion interface
JEMLab 2.0 is PC software developed by the electromagnetic sensing technology laboratory of Jilin University for preprocessing magnetic measurement data of the Overhauser magnetometer. Its main interface and GPS projection coordinate conversion module are shown in Figure 5-6.
5. Conclusion
In this paper, by studying the mathematical principles of Gauss-Krüger projection and UTM projection, the precise conversion of Gauss-Krüger projection coordinates and UTM projection coordinates to the WGS-84 geodetic coordinates are realized by programming with VC++6.0. It is verified by the examples that both forward projection calculation errors are less than 1.0m. The error of Gauss inverse calculation is less than $10^{-3}$ degrees, while the error of UTM coordinate inverse calculation is less than $10^{-5}$ degrees. Based on this, the calculation program for batch conversion of multiple data can be further programmed to provide efficient and convenient application of magnetic GPS coordinates.

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References
[1] Deakin, R. E., Hunter, M. N., Karney, C. F. F. (2010) The Gauss-Krüger Projection. In: The 25th International Cartographic Conference. Paris. pp. 1-21.
[2] Hofmann, B., Lichtenegger, H., Collins, J. (2001) GPS theory and practice. Spring Wien, New York.
[3] Dorrer, E. (2003) From elliptic arc length to Gauss-Krüger coordinates by analytical continuation. In: Grafarend, E.W., Krumm, F.W., Schwarze, V.S. (Eds.), Geodesy-The Challenge of the 3rd Millennium. Springer, Berlin, Heidelberg. pp. 293-298.
[4] Kawase, K. (2011) A general formula for calculating meridian arc length and its application to coordinate conversion in the Gauss-Krüger projection. Bulletin of the Geospatial Information Authority of Japan, 59: 1-13.
[5] Kong, X. Y., Guo, J.M. (2005) Geodesy Basis. Wuhan University Press, Wuhan.
[6] Langley, R. B. (1998) The UTM grid system. GPS World, 9: 46-50.
[7] Dozier, J. (1980) Improved algorithm for calculation of UTM and geodetic coordinates. NOAA Technical Report NEES 81. pp. 1-19.