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评　　语

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Abstract

With the rapid development of GNSS-led spatial positioning technology, the current use of GNSS receivers can obtain coordinate results under the WGS-84 or ITRF coordinate system on a global scale, but this coordinate result cannot be directly used in our country's coordinate system. Therefore, it is of great practical significance and research value to study the conversion relationship between different coordinate systems, solve various coefficients, and convert all the measured results and coordinate data to the same benchmark.

Because of some historical factors, different countries and regions differ in their adoption of the reference ellipsoid, and as a result, there appear a variety of geodetic coordinate systems. China has adopted different coordinate systems in different historical periods. At present, the geodetic control points used in surveying, engineering design, engineering planning and other purposes in China are generally based on Beijing 54 coordinate system or Xi'an 80 coordinate system. Only by understanding the ellipsoid parameters, characteristics and application scope of various coordinate systems in detail, and studying their mutual conversion mathematical models, including the model selection of coordinate system conversion, benchmark selection, method selection and parameter selection, can we better serve the development of my country's surveying and mapping industry and make due contributions to the construction of the national economy. The current problem lies in converting the existing measurement results between Beijing 54 coordinate system, Xi'an 80 coordinate system and local independent coordinate system, and finally converted to the 2000 national geodetic coordinate system, so as to realize the sharing of geographic information and avoid redundant construction to reducing waste of resources. In order to realize the mutual conversion between commonly used coordinate systems in our country and the mutual conversion between local independent coordinate systems and the above-mentioned coordinate systems, this paper proposes the subject of coordinate conversion.

In order to study the conversion relationship between different coordinate systems and analyze the influencing factors, so as to realize the high-precision conversion between various coordinate systems, ensure that the surveying and mapping results can be accurately transferred to the target coordinate system and make full use of the existing surveying and mapping results and data, the main work of this thesis is as follows. Based on the basic theory of the earth ellipsoid, the coordinate system is simply classified (geocentric coordinate system, reference coordinate system, local

independent coordinate system), the commonly used coordinate system in China is introduced (Beijing coordinate system in 1954, Xi'an coordinate system in 1980, WGS-84 coordinate system, CGCS2000 coordinate system), and the conversion method between different coordinate systems is described. The conversion methods between systems include: mutual conversion between geodetic coordinates and spatial rectangular coordinates; mutual conversion between geodetic coordinates and plane coordinates; mutual conversion and parameter calculation between different spatial rectangular coordinate systems.

According to the relevant theoretical knowledge and the conversion method of different coordinates, a full-featured measurement coordinate conversion software is designed using the C# window application program, which can realize the measurement coordinates between different measurement coordinates under the same reference ellipsoid and between different reference ellipsoids. Mutual conversion, that is, the conversion between geodetic coordinates and spatial rectangular coordinates, the conversion between different spatial rectangular coordinate systems, the mutual conversion between geodetic coordinates and plane coordinates, and a series of conversion functions such as coordinate conversion calculation. The system is easy to operate and has a friendly interface. It takes both single-point conversion and batch conversion into account, and its accuracy can meet the requirements of daily surveying and mapping work. Finally, the function demonstration, case data inspection and comparative analysis of the developed software are carried out. The results show that the software developed in the thesis has powerful functions and reliable coordinate conversion accuracy.

Keywords: coordinate system, coordinate transformation, Gaussian plane projection, seven-parameter model, measurement coordinate transformation system

摘 要

随着以 GNSS 为主导的空间定位技术的迅猛发展，当前使用 GNSS 接收机在全球范围内都能获取 WGS-84 或 ITRF 坐标系下的坐标结果，但此坐标成果无法直接用到我国的坐标系统中，因此研究不同坐标系统之间的转换关系，求解各种系数，将所有测量所得的成果，坐标数据转换到同一个基准下，具有重要的现实意义和研究价值。

本文从椭球的基本几何参数和我国常用的几种坐标系（1954 年北京坐标系，1980 西安坐标系，WGS-84 坐标系，CGCS2000 坐标系）的建立方法与基本理论知识出发，探讨不同坐标系之间的转换方法，包括：大地坐标与空间直角坐标相互转化；大地坐标与平面坐标之间的相互转换；不同空间直角坐标系之间的相互转换与参数计算。

根据相关的理论知识和不同坐标的转换方法，利用 C#窗口应用程序设计了一套功能齐全的测量坐标转换软件，能够实现同一参考椭球下和不同参考椭球之间的不同测量坐标之间的相互转换，即大地坐标与空间直角坐标相互转化，不同空间直角坐标系之间的转换；大地坐标与平面坐标之间的相互转换。要求软件操作方便、界面友好,兼顾单点转换与批量转换，并保证精度满足日常测绘工作的要求。并对软件各个功能板块进行测试。

关键词：坐标系，坐标转换，高斯平面投影，七参数模型，测量坐标转换系统

Application of GNSS in weather forecast

With the development of the Global Navigation Satellite System (GNSS), its application range has gradually expanded, covering almost every field. Such as geographic data collection, surveying and mapping, vehicle monitoring and dispatch navigation services, aviation navigation, military and so on. In addition, GNSS also plays an important role in weather forecasting. In the early 1990s, an idea emerged: Since the GNSS signal is affected by the atmosphere, can the signal received by the GPS receiver be used to inversely calculate the concentration of electrons and water vapor in the atmosphere, thereby achieving the effect of weather forecasting. Experiments have confirmed that the use of GNSS observations can inversely calculate the atmospheric water vapor content and make meteorological predictions. Therefore, GPS meteorology was born, which is a knowledge system that uses GPS signals to measure and analyze atmospheric conditions. Next, I will introduce the weather forecast function of GNSS. The content is based on a journal "Establishing a method of short-term rainfall forecasting based on GNSS-derived PWV and its application", written by Yibin Yao, Lulu Shan and Qingzhi Zhao.

Water vapor is an important part of the atmosphere. There are many methods to detect the content and distribution of water vapor in meteorology, such as radiosonde technology (Radiosonde), water vapor radiometer (WVR), satellite remote sensing detection and so on, but due to various reasons, they have defects in reflecting the distribution of atmospheric water vapor. As a real-time, all-weather, global and low-cost technology, GNSS technology is also a suitable tool for measuring water vapor content. Researching the basic principles and methods of using GNSS technology to calculate and obtain atmospheric water vapor content is conducive to accurately predicting the law of weather changes and future trends, and promoting the application of GNSS meteorology in climate monitoring and weather forecasting. Next, I will specifically introduce this method of using GNSS technology to accurately detect atmospheric water vapor content, atmospheric inversion, which called water vapor inversion (PVW).

Water vapor inversion (PVW) is a method of using the data detected by meteorological satellites or other remote sensing methods to obtain the content or distribution of water vapor in the atmosphere from the radiation transfer equation. As a new interdisciplinary subject, GNSS meteorology not only improves the temporal and spatial resolution and accuracy of obtaining atmospheric parameters, but also greatly reduces the observation cost. Therefore, GNSS meteorology has very good application prospects.

The calculation principle and accuracy check method of atmospheric water vapor are as follows. The influence of tropospheric delay on GPS signal can be divided into static water part and wet part:

$$ZTD = ZHD + ZWD \tag{1}$$

Where, ZTD is the total zenith delay, ZHD is the zenith hydrostatic delay, and ZWD is the zenith wet delay.

Many scholars at home and abroad have studied the tropospheric delay model. The most researched empirical models include the Hopfield, Saastamoinen, Black model, etc. Now the Saastamoinen model is introduced.

$$\begin{cases} ZWD = 0.002277\left(\frac{11255}{\mathrm{T}} + 0.05\right) \times \frac{e_0}{F(\varphi, h_0)} \\ ZHD = 0.002277 \times \frac{P_0}{F(\varphi, h_0)} \\ F(\varphi, h_0) = 1 - 0.0026\cos 2\varphi - 0.0028 h_0 \end{cases} \tag{2}$$

Where, P_0 is the air pressure at the station (mBar); T is the temperature at the station (K); e_0 is the vapor pressure at the station (mbar); φ is the latitude of the station; h_0 is the elevation of the station (km). Research shows that given the meteorological parameters on the surface of the station, the accuracy of calculating the station zenith dry delay using the above formula can reach 1~2mm, while the error of wet delay can reach 2~5cm.

The dry atmosphere is relatively stable, so the dry delay can be accurately estimated based on various empirical models to separate the wet delay from the total delay. After obtaining the wet delay, it can be further transformed into meteorological-related atmospheric precipitable volume (PWV), and their relationship can be expressed as:

$$\mathrm{PWV} = \pi \cdot \mathrm{ZWD} \tag{3}$$

$$\pi = \frac{10^6}{\rho_w R_v \left[K_3/T_m + K_2'\right]} \tag{4}$$

Where, ρ_w is the density of liquid water, $10^3 kg/m^3$; R_v is the gas constant of water vapor, usually $461.495 J\cdot kg^{-1}\cdot k^{-1}$; k_2', k_3 are the refractive index of the atmosphere, $k_2'=22.13\pm2.20$ $K\cdot hPa^{-1}$, $k_3=3.739\times105$ $K\cdot hPa^{-1}$; T_m is the weighted average temperature of the atmosphere, in K. Other parameters except T_m are constants, so how to accurately obtain the weighted average temperature T_m of the tropospheric atmosphere is particularly important, and T_m varies at different times and in different regions. The average temperature T_m is particularly important, and T_m varies at different times and in different regions.

$$T_m = \frac{\int (e/T)dz}{\int (e/T)dz} \tag{5}$$

Where, e is the water vapor pressure, T is the absolute temperature, and dz is the integral path.

Generally, it can be calculated by empirical equation from Bevis6 using the ground temperature Ts as follows

$$T_m = a + bT_s \tag{6}$$

The equation is usually established under the constraints of sounding data and reanalysis data in the specific area.

The author compared the data from the Zhejiang CORS network weather station with the PWV series calculated by the Precision Point Positioning (PPP), and got a series of conclusions. When rainfall occurs, the PWV will increase, but not all high PWV values indicate the occurrence of rainfall. The rise of water vapor is only one of the necessary prerequisites for rainfall to occur. Some external dynamic factors, such as thermodynamic changes, are also necessary to trigger rainfall. If the conditions of external dynamic factors cannot be met, even if the GNSS/PWV value is at a high level, rainfall events may not occur. There is no obvious correspondence between the size of precipitation and the size of GNSS/PWV, but the rapid change of GNSS/PWV indicates that the rainfall is coming, and the PWV change range of more than 5mm per hour indicates that the rainfall is coming. When the PWV rises and stays above 50mm, once it starts to fall, there will be heavy rain in the area.

The author verifies the feasibility and reliability of this prediction method through examples. This method can predict rainfall 6 hours in advance and can detect about 80% of rainfall events. However, the relationship between PWV and rainfall is different in different regions and at different times, which brings difficulties to weather prediction. This requires statistics to obtain the PWV thresholds for heavy precipitation in different seasons for reference by weather forecasters. The weather forecast system based on GNSS technology is not mature enough, and the official operation of the Beidou system also helps this forecasting system to be more perfect. However, due to the limitations of various factors, this forecasting system still has many shortcomings, which need us to continue to study.

The focus of subsequent research is to study various errors and improve the model to improve the calculation accuracy of water vapor content. The weather is complex and changeable, so we need to consider a variety of factors and additional conditions to achieve the best prediction effect. GNSS applications are diverse. The number of possible GNSS applications is not limited by technology rather than by our imagination. And the development of satellite navigation is not finished.