Modernizing Field Surveying: The Role and Impact of GNSS-RTK Technology in Digital Mapping

Ananya Patel

University of Delaware
patelananya@delaware.edu

Abstract: The field of surveying and mapping has undergone significant transformations with the development of electronic devices like total stations, GNSS systems, digital cameras, and computers, shifting from traditional analog measurement methods to digital mapping. GNSS-RTK technology, a cornerstone in this digital transition, offers a more efficient approach to field data collection compared to traditional methods and is extensively utilized in topographic surveying. The continuous advancements in GNSS technology have streamlined the production process, making it both faster and more convenient. Additionally, the introduction of RTK technology has overcome the constraints of conventional measurement techniques by enabling precise positioning within the coverage of reference station networks, thus fostering deeper integration of RTK technology in traditional surveying fields. GNSS-RTK technology not only enhances efficiency and accuracy but also simplifies data storage and subsequent modifications, maintaining the modern trends in mapping results. This paper explores the methodology, applications, and accuracy of GNSS-RTK technology in field data acquisition.

Keywords: GNSS-RTK technology; Precision analysis; GNSS-RTK application; High-precision positioning.

1. Introduction

Due to the development of China's social economy, the total number of construction projects is also increasing, and construction projects are inseparable from surveying and mapping projects, with more and more problems in construction projects, surveying and mapping is becoming more and more difficult, in this process of continuous development, if still using traditional measurement methods has been difficult to meet the measurement needs. For example, in the determination of Mount Everest, it is already difficult to determine its height by traditional methods, and in order to meet the measurement needs, digital mapping technology was born.

At present, more and more high-tech applications in the field of surveying and mapping, a variety of high-tech surveying and mapping instruments are numerous, of which GNSS-RTk is one of the most commonly used methods, is every engaged in surveying and mapping industry must be proficient in use, the emergence of each high-tech surveying and mapping instrument will bring new surveying and mapping technology. Although there are many kinds of high-tech surveying and mapping instruments in the world, RTK is currently the most used surveying and mapping instrument in China, and GNSS-RTK technology is also China's mainstream mapping technology, which is used by the majority of surveyors and mapping workers. Although there are other more advanced mapping technologies, they have certain limitations considering that the cost of using other mapping technologies is too high. And the environmental requirements are relatively high. Therefore, given the low cost of GNSS-RTK, the environmental requirements are not high. GNSS-RTK still occupies the dominant position of surveying and mapping instruments in China. GNSS-RTK technology is a surveying technique that every surveyor must master proficiently.

Compared with traditional mapping technology, GNSS-RTK technology has the characteristics of high precision, simple control, portable equipment and all-weather work, which can realize accurate navigation and real-time rapid recording of points, ensure the accuracy and timeliness of lofting, ensure that points will not affect each other, and effectively avoid the accumulation of various errors. It is more accurate and easier to operate. In addition, when using GNSS technology to carry out engineering surveying work, due to good environmental applicability, construction monitoring can be carried out in various areas with dangerous terrain and poor measurement conditions, and remote control can be carried out without the need for survey technicians to arrive at the survey site, the difficulty of construction monitoring is greatly reduced, and the cost of testing is relatively low. Moreover, it is convenient, fast and accurate in field data collection; It has many advantages such as rich information, easy to save, query, modify, calculate, and design on the internal industry map. Therefore, at present, GNSS-RTK technology is widely used in education and scientific research, national defense construction, national economic engineering and other fields.

2. Basic structure of GNSS-RTK

The basic components of GNSS-RTK are generally divided into receiving devices, transmission devices, and related processing software. At present, most of the receivers use dual-frequency machines, and the transmission devices are currently more types, most of which are in the form of radio stations, and the widely distributed GSM signal is also mentioned in the urban vehicle control system as the main transmission carrier, and the signal zero-point five diameter of the radio station will also affect the size of the RTK operating area. The basic functions of the processing software must meet the following conditions: (1) can quickly count the unknown quantities throughout the week; (2) convert the coordinate system and elevation system; (3) can count the position of the user standing under WGS-84; (4) the quality of the calculation results is tested and analyzed; and (5) the data is represented and mapped.

3. GNSS-RTK measurement method

In the realm of GNSS-RTK technology, different methodologies and setups can dramatically affect the outcomes of surveying projects, particularly in terms of accuracy and reliability of the data obtained. Two notable approaches in handling coordinate systems and data transformation are the no projection/no replacement algorithm and the typed parameter method. Here's a more detailed examination of each approach:

1. No Projection / No Replacement Algorithm:

This method allows the direct use of GNSS receivers to obtain the WGS-84 coordinates from both the base station and the rover without needing the base station to be positioned at a known point. This is particularly advantageous in environments where setting up a base over a known marker is impractical. The core of this approach involves using the WGS-84 coordinates (a global coordinate system used by GPS technology) of a monitored location and converting these to a local coordinate system using a specific mathematical model. This conversion is critical in applications like large-scale land surveying and infrastructure monitoring, where localized data is more relevant and actionable.

However, a significant challenge with this approach is that it requires monitoring a considerable number of known points simultaneously to ensure accuracy. The transformation model must be robust enough to handle variations and potential discrepancies that arise from using multiple known points. This can complicate the setup but is necessary for maintaining the integrity of the transformation process, ensuring that the localized coordinates are accurately calculated from the global positioning data.However, a significant challenge with this approach is that it requires monitoring a considerable number of known points simultaneously to ensure accuracy. The transformation model must be robust enough to handle variations and potential discrepancies that arise from using multiple known points. This can complicate the setup but is necessary for maintaining the integrity of the transformation process, ensuring that the localized coordinates are accurately calculated from the global positioning data.

2. Typed Parameter Method:

This method involves manually entering the WGS-84 and local coordinates obtained from static observations into a computational handbook. Following this, the entered data undergo transformation based on predefined conversion parameters, typically derived from prior static observations where elevation adjustments are noted. The base station in this setup must be erected at a precisely known point, ensuring that its global coordinates align with the local datum used in the survey.

One of the limitations of this method is that while the base station's position is fixed and known, it does not allow for the concurrent monitoring of other known points for verification purposes during active survey operations. However, it is recommended to periodically verify the accuracy of the transformation parameters by measuring a number of known points at convenience. This verification helps in adjusting and recalibrating the transformation parameters to adapt to any local changes or discrepancies that might not have been initially apparent.

Both methods offer distinct advantages and come with their own set of challenges. The choice between these methods typically depends on the specific requirements of the survey, the geographical and environmental conditions of the survey area, and the level of precision required for the project. In practice, a hybrid approach may sometimes be employed, combining elements of both methods to optimize the accuracy and efficiency of the surveying process while adapting to the dynamic nature of field conditions. This blending of methodologies is part of the ongoing evolution within the surveying and mapping industry as it adapts to new technologies and methodologies.

4. Application of GNSS-RTK in data acquisition

4.1. Application of GNSS-RTK in horizontal displacement monitoring of dams in port engineering

4.1.1. Monitoring point lofting application

Most of the port engineering embankment monitoring projects are far from the shore, the location of the reference point needs to be set in a stable area not affected by construction on land, its location is far from the construction site, the working base point and the reference point are far away and affected by the site environment, and the reference point is often limited by conditions cannot be completely visible, so the use of traditional total station for lofting requires multiple transfers, after multiple transfers, its accuracy is greatly reduced and time-consuming. For the Qinzhou Port East Waterway Expansion Project Blowing and Filling Area Leveling Project Embankment Deformation Monitoring Project, at the beginning of the project, the on-site monitoring point lofting method was used by the total station polar coordinate lofting method. Because the lofting points of the embankment are far apart, and the lofting distribution is irregular, when using this lofting method, it is necessary to calculate the distance and angle of the reference point in advance to accurately complete the lofting of the on-site monitoring point. Compared with other types of lofting methods, although polar lofting of total stations can improve lofting efficiency to a certain extent, the improvement range is very limited.

4.1.2. Horizontal displacement static measurement applications

Horizontal Displacement Static Measurement Reliability Analysis As far as the embankment monitoring is concerned, most of the horizontal displacement monitoring work is done by the total station. However, because the horizontal displacement measurement using the total station is based on the polar coordinate method, the observation results will inevitably be changed by changes in observation distance and visual conditions. In contrast, the GNSS-RTK measurement method can transmit signals with the help of its satellites,which can effectively avoid the drawbacks of total stations in the application of horizontal displacement monitoring of embankments.

4.2. Application of GNSS-RTK in gas pipelines

The two most common functions of GNSS-RTK equipment in the gas industry are broken step detection and spot lofting, and the following will focus on the use of these two functions. One step measurement function application: (1) as-built measurement. Completion survey refers to the establishment of a database of measurement data and project-related data information by internal personnel after all field surveys and acceptance before the gas pipeline is covered with soil. The location data and related attribute data of the pipeline after the library are compressed into the GIS management system database, and this information is combined with terrain information to form the basic information of the GIS management system. The information system can provide basic data management support for pipeline information operation and maintenance management, design, customer development and other work in the later stage: (2) pipeline information and equipment census data analysis. Census data mapping was carried out for the old pipeline equipment that had been laid and built, and the GNSS-RTK technology and pipeline detector were used to detect old and obsolete pipelines as the basic elements, and the data was submitted to the GIS management system to maintain the integrity of urban gas digital pipeline information. (3) Pipeline checking. Since third-party construction and pipeline transformation need to carry out pipeline construction, if the buried pipeline is exposed, the GNSS-RTK device can be used to achieve accurate positioning, and the location coordinates can be corrected with the corresponding pipe position in the GIS management system, and the correctness of the GIS system data can be known, and the pipelines and devices with large deviations in the GIS management system are effectively checked and corrected, and the authenticity of pipeline data is improved through large-scale excavation and verification. (4) Important data marking. For pipeline emergency repair, maintenance and other working conditions, GNSS-RTK can be used to monitor and change pipeline conditions and facilities, record relevant information such as emergency and maintenance points, establish relevant thematic layers in the GIS management system, and use powerful data processing risk analysis and comprehensive assessment of pipeline conditions, so as to facilitate the implementation of later maintenance and other management work.

4.3. Application of GNSS-RTK in road survey

The GNSS positioning method has shown strong socio-economic benefits and scientific and technological superiority because of the technical advantages of the measurement point without mutual visibility, the measurement work process is manual, all-weather, the data is accurate, the work is efficient, and the connection mode and accuracy between the ground points have little to do with it, and it shows strong socio-economic benefits and scientific and technological superiority. The application of GNSS in road survey is as follows

The layout of the control network should be carried out according to the topographic conditions of the measured area and the actual condition of the measuring device owned by the operating unit, and the two factors of the operation effect and the required economic cost should be taken into account.

In the case that the sky of the survey area is relatively wide, the GNSS method should be used as an option, that is, when the GNSS technology is used to realize the work of laying the control network, the known position should be laid first, and then the wire should be used to detect, and the encrypted action of the laid control network should be completed. Once the operators who have realized the deployment of the control network have enough GNSS technology, they cannot take the step-by-step measurement method, or they can directly use the GNSS method to lay out all the control areas once.

1). The monitoring operation of GNSS and field monitoring GNSS must be prepared in advance and unified scheduling instructions during operation, but because the actual situation is more complicated, it needs to be handled flexibly during implementation. For the GNSS point observation work carried out according to the technical conditions of one minus three-layer conductor, under the premise of strictly implementing the predetermined operation plan, the measurement section and public station settings can be changed according to the observation requirements of the measuring station, road conditions, the length of the building baseline, etc., and the monitoring period can be reduced or extended accordingly.

2). Baseline and Variance Work Although the software used to achieve baseline solution and differential work is different, it can be divided into the following process in general. (1) Inject data related to observations made by GNSS receivers into the computer. (2) By setting appropriate solution parameters, the baseline solution work is realized. (3) Complete the unqualified baseline solution again by setting the appropriate technical parameters. (4) Measure accuracy to the baseline of GNSS. (5) Complete the mutual conversion between the two-dimensional adjustment and the coordinate map system. (6) Convert the earth height to normal elevation through teaching fitting

In the case that the sky of the survey area is relatively wide, the GNSS method should be used as an option, that is, when the GNSS technology is used to realize the work of laying the control network, the known position should be laid first, and then the wire should be used to detect, and the encrypted action of the laid control network should be completed. Once the operators who have realized the deployment of the control network have enough GNSS technology, they cannot take the step-by-step measurement method, or they can directly use the GNSS method to lay out all the control areas once.

3). The monitoring operation of GNSS and field monitoring GNSS must be prepared in advance and unified scheduling instructions during operation, but because the actual situation is more complicated, it needs to be handled flexibly during implementation. For the GNSS point observation work carried out according to the technical conditions of one minus three-layer conductor, under the premise of strictly implementing the predetermined operation plan, the measurement section and public station settings can be changed according to the observation requirements of the measuring station, road conditions, the length of the building baseline, etc., and the monitoring period can be reduced or extended accordingly.

4). Baseline and Variance Work Although the software used to achieve baseline solution and differential work is different, it can be divided into the following process in general. (1) Inject data related to observations made by GNSS receivers into the computer. (2) By setting appropriate solution parameters, the baseline solution work is realized. (3) Complete the unqualified baseline solution again by setting the appropriate technical parameters. (4) Measure accuracy to the baseline of GNSS. (5) Complete the mutual conversion between the two-dimensional adjustment and the coordinate map system. (6) Convert the earth height to normal elevation through teaching fitting

5.Summary

The landscape of GNSS-RTK digital mapping technology is continually reshaped by rapid advancements in science and technology, indicating that the cumbersome tasks associated with traditional surveying methods are poised to become more streamlined in the foreseeable future. This evolution holds significant promise for the future of surveying and mapping, potentially leading to the emergence of new, more sophisticated technologies that could eventually supplant GNSS-RTK as the standard. Nonetheless, the current context within which GNSS-RTK operates, particularly in China, underscores its ongoing relevance and centrality.

GNSS-RTK (Global Navigation Satellite System - Real Time Kinematic) technology remains a cornerstone in the surveying and mapping industries due to its high accuracy, efficiency, and real-time data processing capabilities. Despite the potential for newer technologies to emerge, GNSS-RTK continues to be indispensable for a wide range of applications including construction, agriculture, urban planning, and environmental monitoring. Its ability to provide precise measurements in real-time makes it particularly valuable in projects requiring high levels of accuracy and efficiency.

Currently, the landscape of satellite navigation systems is dominated by the U.S.-controlled GPS, which presents a significant cost factor, especially outside the United States where access fees or technology transfer costs can be prohibitive. China's response to this dominance is the development of its own satellite navigation system, Beidou. Although Beidou is still in the stages of full operational capability and global integration, its completion and optimization could shift the dynamics of technological dependency and open up new avenues for innovation in GNSS technologies.

As Beidou continues to develop and integrate into global satellite navigation systems, it is expected to provide a viable alternative to GPS, especially in the Asia-Pacific region. This development not only promises to reduce costs associated with GNSS-RTK technology but also enhances China's autonomy and influence in global satellite navigation. Moreover, the integration of Beidou is likely to foster more localized innovations in GNSS-RTK technologies, tailored to specific regional needs and challenges.

Looking forward, the surveying and mapping sector may witness the introduction of technologies that leverage artificial intelligence, machine learning, and increased automation. These technologies could offer even greater accuracies, reduce human labor costs, and streamline data processing and analysis. Innovations such as unmanned aerial vehicles (UAVs) and autonomous vehicles equipped with advanced sensing technologies could also redefine traditional surveying methods.

The evolution from GNSS-RTK to more advanced systems carries significant socio-economic implications, particularly in terms of improving the efficiency of large-scale infrastructure projects, enhancing land management capabilities, and supporting sustainable development initiatives. The potential reduction in costs and the democratization of access to high-quality surveying technologies could also have profound impacts on developing countries, enabling more comprehensive participation in global economic systems.

In summary, while GNSS-RTK digital mapping technology currently holds a pivotal role in China's surveying and mapping efforts, the ongoing advancements in satellite technology and digital mapping suggest a future where even more advanced systems could enhance or replace current methodologies. The evolution of Beidou and other technological innovations will be key factors in shaping the future landscape of digital mapping and surveying technologies.

References

[1] XU Dingjian. Application and accuracy analysis of GNSS-RTK control measurement[J]. Low Carbon World,2021(7):70-72.

[2] Liu Zhiwei. Application of GNSS-RTK in urban surveying [J]. Urban Architecture Theory Research (Electronic Edition), 2020(7): 82-83.

[3] Huang Hai. Application analysis of GNSS-RTK technology in horizontal displacement monitoring of port embankments [J]. Pearl River Water Transport,2022(4):17-19.

[4] Cheng Weishan, Application of GNSS-RTK in gas pipelines[J].China Petroleum and Chemical Standards and Quality,2022(1):115-117.

[5] Construction Technology,2007(7):412-413.

[6] Gu Xiaolie, Bao Feng, Cheng Xiaojun, Surveying (3rd ed.)[M], Shanghai: Tongji University Press, 2009.