Journal of Computing and Electronic Information Management
ISSN: 2413-1660 | Vol. 21, No. 2, 2026

Research on 3D Geological Modeling Methods Based on Big Data Analysis

Yibing Lu

Institute of Resource and Environment, Henan Polytechnic University, Jiaozuo 454003, Henan, China

Abstract: With the advent of the big data era, the scale and complexity of geological data have been continuously increasing. Traditional geological modeling methods can no longer meet the demands for high precision and high efficiency. Therefore, proposing new methods for 3D geological modeling based on big data analysis has become particularly important. This paper focuses on the collection and processing of big data, explores the application of big data analysis technologies in 3D geological modeling, and further proposes a 3D geological modeling algorithm based on big data analysis to improve modeling accuracy and visualization capabilities. Future research can further explore big data analysis methods and technologies in 3D geological modeling to promote development and innovation in the field of geology.

Keywords: 3D geological modeling; Big data analysis; Modeling accuracy; Application.

1. Introduction

Big data technology is a novel product emerging in the context of the “Internet+” era. By adopting new approaches to data utilization, and with the continuous advancement of internet technologies, the volume and variety of data have been rapidly increasing. As a result, big data analysis has become a new research hotspot, capable of uncovering patterns and correlations that are difficult to detect using traditional analytical methods.

In the field of geology, three-dimensional (3D) geological modeling has been widely applied in petroleum, mineral resources, and water resources. Big data analysis provides enhanced data support and advanced visualization tools, further expanding the research scope and application of 3D geological modeling. In geological exploration and mineral resource development, big data analysis is also playing an increasingly important role. Traditional methods in these fields largely rely on manual experience and field investigations, which suffer from low efficiency, high costs, and limited identification accuracy. Therefore, improving the efficiency and accuracy of geological exploration and mineral development through big data analysis has become a new development direction in geological research.

3D geological modeling is one of the core technologies in geological exploration and mineral development. By digitizing geological data, it constructs realistic 3D geological models that provide comprehensive insights into geological structures and ore body characteristics. However, traditional 3D geological modeling methods rely heavily on manual interpretation and hand-drawn representations by miners and geological engineers, resulting in difficulties in identification, low efficiency, and poor reproducibility. These limitations pose significant challenges to geological exploration and mineral development and restrict the efficient utilization of mineral resources.

Therefore, the research and application of 3D geological modeling methods based on big data analysis have become particularly important. By leveraging massive geological datasets and machine learning techniques, these methods enable more accurate and efficient construction of 3D geological models, further promoting the digitalization of geological mapping and improving the efficiency and accuracy of exploration and resource development.

At present, 3D geological modeling methods based on big data analysis play an important role in three aspects: digital processing, data mining and analysis, and machine learning technologies. Although this field is still under continuous development and improvement, the advancement of big data analysis techniques and machine learning algorithms will provide stronger support for geological exploration and mineral resource development in the future.

2. Overview of Google’s Classic Big Data Papers

In the development of distributed systems for big data, Google has published three influential papers, namely GFS (Google File System), MapReduce, and BigTable.

2.1. Google File System

GFS describes the design principles of the Google File System. It is a scalable distributed file system designed for large-scale, data-intensive applications. While it shares some similarities with traditional distributed file systems, it also introduces many new design concepts, which can be regarded as an upgraded “2.0 version” of earlier systems.

The collaborative design between applications and the file system API enhances overall system flexibility, allowing multiple clients to perform append operations simultaneously rather than sequentially, while still ensuring data consistency. This provides significant convenience in practical use. For example, collaborative online documents (such as multi-user editing platforms) allow multiple users to edit simultaneously, greatly improving work efficiency. The API serves as an interface provided by the operating system for applications, enabling programs to run through system calls.

2.2. Simplified Data Processing for Large Clusters

MapReduce can be regarded as a programming model and a novel big data computing method. In simple terms, it divides a large problem into multiple smaller subproblems, solves them independently, and then aggregates the results. This process also involves task allocation and result integration.

Similarly, programs based on the MapReduce architecture can be executed in parallel across numerous computers. Massive datasets (on the order of terabytes) are partitioned and distributed to thousands of machines for processing, achieving efficient data decomposition and recombination.

2.3. Structured Data

BigTable is a distributed storage system for structured data, designed to store and process massive datasets. Structured data refers to data organized and stored according to predefined schemas. It has clearly defined formats and layouts, making it easy for computer systems to interpret and process.

Structured data typically exists in the form of tables, databases, or spreadsheets, where each data field has a specific data type and associated attributes. It has four main characteristics:

(1) a well-defined schema;

(2) multiple data fields, each with its own name and data type for storing specific types of data;

(3) ease of querying and analysis;

(4) enforceable requirements for data consistency and integrity, meaning that data must conform to predefined standards during storage and processing to ensure accuracy and reliability.

In summary, this paper, combined with the current research direction, explores 3D geological modeling methods based on big data analysis, investigates their applications and prospects in the field of geology, and aims to provide references and insights for further research.

3. Application of Big Data Analysis in 3D Geological Modeling

Traditional embroidery art still has wide application value in contemporary fashion design.

3.1. Concept and Characteristics of Big Data Analysis

Big data analysis refers to methods and technologies for processing and analyzing large-scale datasets. It involves the collection, storage, processing, and interpretation of vast amounts of structured and unstructured data in order to uncover valuable information and hidden patterns.

(1) Big data analysis has the following characteristics:

Large-scale datasets: Big data analysis deals with massive datasets in terms of both data volume and data sources. These data can originate from multiple channels, including social media, sensors, and log files.

(2) Diversity and complexity: Big datasets typically contain various types and formats of data, such as text, images, audio, and video. These data may include noise, missing values, and errors, requiring cleaning and transformation before effective analysis.

(3) Real-time or near-real-time analysis: Big data analysis often requires rapid data processing and analysis within a short time frame to extract useful information from real-time or near-real-time data. This necessitates efficient algorithms and technologies for fast processing and response.

(4) Data value and decision support: The goal of big data analysis is to extract trends, patterns, and insights from large datasets to support decision-making and solve practical problems. This can help organizations optimize business processes, identify market opportunities, and improve products and services.

(5) Data privacy and security: Since big datasets may contain sensitive information, such as personal identity data and business secrets, privacy and security are critical concerns. Appropriate measures must be taken to ensure data confidentiality and integrity.

Overall, by processing large and complex datasets, big data analysis provides valuable information that facilitates decision-making and problem-solving.

3.2. Roles and Significance of Big Data Analysis in 3D Geological Modeling

Big data analysis plays an important role in 3D geological modeling, with the following functions and significance:

(1) Data acquisition and integration: Big data analysis helps geologists collect and integrate large volumes of geological data, including geophysical exploration data, drilling data, and geological–geochemical data. These data originate from diverse sources and vary in type; big data techniques enable their integration into a unified dataset, providing comprehensive geological information. As illustrated in Figure 1, multi-source attribute data are collected to construct 3D geological models.

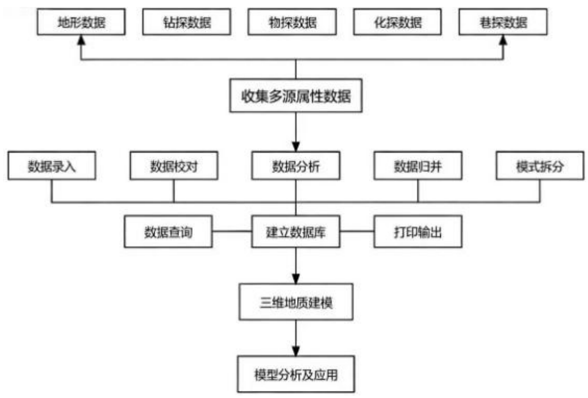

Fig 1 Workflow of data acquisition and model construction

(2) Geological model construction: Big data analysis can be applied to geological modeling by utilizing large-scale datasets for model building and prediction. Through data analysis and modeling, it is possible to reveal the complexity of subsurface geological structures, lithological composition, and geological processes, thereby helping scientists better understand Earth evolution and resource distribution.

(3) Risk assessment and prediction: Big data analysis supports geological risk assessment and forecasting. By analyzing extensive datasets on historical earthquakes, volcanic eruptions, and geological hazards, models and algorithms can be developed to predict potential future disasters and enable preventive measures in advance.

(4) Resource exploration and development: Big data analysis provides more accurate evaluation and prediction of subsurface resources. By analyzing geological exploration data, geophysical data, and other related datasets, it becomes possible to identify the distribution of potential mineral and energy resources, thereby guiding resource development and improving exploration efficiency and success rates.

(5) Intelligent decision support: Big data analysis offers decision support in 3D geological modeling. Through in-depth mining and analysis of large-scale geological data, it provides insights into geological features, processes, and subsurface structures. Such information supports decision-

makers in formulating strategies for geological engineering projects, reducing risks, and improving project success rates.

In summary, big data analysis helps address the complexity and diversity of geological data in 3D geological modeling while providing deeper geological insights and decision support. It is of great significance for geological engineers, resource developers, and environmental managers.

3.3. Application of Big Data Analysis

3.3.1. Application of Big Data Analysis in Geological Processing

Big data analysis has a wide range of applications in geological processing, including geological exploration, earthquake monitoring and prediction, geological risk assessment, geological engineering projects, and geological environment monitoring.

First, in terms of geological exploration, big data analysis supports geological exploration activities. By analyzing massive geological, geophysical and geochemical data, it reveals the distribution of underground resources, structural characteristics and favorable geological conditions. Such analysis can guide the exploration of oil, natural gas, mineral resources and other resources.

In addition, big data analysis can be applied to earthquake monitoring and prediction. By analyzing the time, location and magnitude of seismic events, models and algorithms of seismic activity can be established to realize earthquake prediction and early warning, which is of great significance for seismic risk management and building seismic design.

Secondly, big data analysis facilitates geological risk assessment, covering geological disasters such as landslides and debris flows, volcanic activities, land subsidence and other geological hazards. Analysis of massive geological data enables the understanding of the temporal and spatial distribution characteristics of geological risks, providing a basis for disaster prevention and mitigation.

Big data analysis is also applicable to geological engineering projects. By analyzing and modeling geological data and underground conditions, it helps designers and engineers better understand underground geological structures and properties, and guides land use planning, infrastructure construction and geological engineering construction.

Moreover, big data analysis can be used for geological environment monitoring, such as water resource management, soil quality evaluation and geological disaster monitoring. Through analyzing massive geological and environmental data, it can monitor environmental changes, grasp the status of underground water resources, and predict potential geological disaster risks.

The applications of big data analysis in geological processing are extensive. All links ranging from exploration, risk assessment and engineering projects to environmental monitoring can benefit from big data analysis technologies and methods. These applications can improve the efficiency and quality of geological work, and enhance the understanding and monitoring level of underground geological conditions.

3.3.2. Application of Big Data Analysis in Model Construction

Big data analysis is also widely applied in model construction, mainly reflected in the following aspects:

(1) Data Cleaning and Preprocessing: Big data analysis enables the cleaning and preprocessing of large-scale datasets to remove noise and handle missing values and outliers. As a crucial step in model construction, data cleaning and preprocessing improve data quality and accuracy, so as to obtain more reliable model results.

(2) Feature Selection and Feature Engineering: By analyzing massive data, big data analysis identifies features and variables that exert the greatest influence on model prediction and analysis [23,24]. Selecting and extracting the most meaningful features can simplify model complexity and improve model prediction accuracy. Meanwhile, big data analysis helps design new feature transformation and engineering methods to better express data characteristics and correlations.

(3) Model Training and Optimization: Big data analysis can be applied to the process of model training and optimization. Training with large-scale datasets can generate more accurate models. In addition, it can be used to adjust model hyperparameters, select appropriate algorithms and optimization techniques, so as to improve model performance and generalization ability.

(4) Model Evaluation and Validation: Big data analysis assists in model evaluation and validation. By analyzing massive data and model outputs, it can assess the prediction accuracy, robustness and reliability of models. It can also be applied to model interpretability analysis, helping explain model prediction results and decision-making processes.

In conclusion, big data analysis can improve model quality and performance through procedures including data cleaning, feature selection, model training and evaluation (as shown in Figure 2). The methods and technologies of big data analysis can deliver more accurate and reliable model predictions and reduce the processing complexity of models on large-scale datasets.

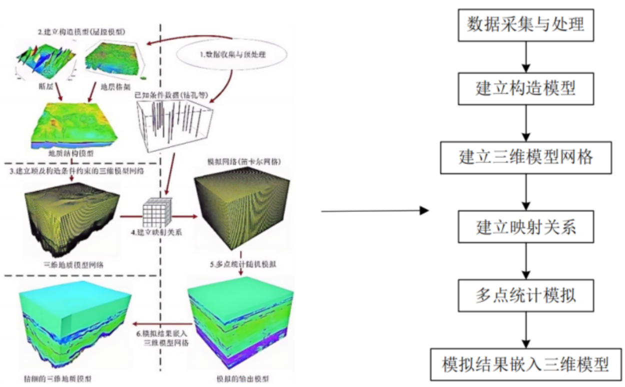

Fig 2. Establishment of 3D Model

4. Construction of 3D Geological Model

4.1. Data Acquisition and Preprocessing

Data acquisition and preprocessing are two essential steps in the big data analysis process. Data acquisition refers to the process of obtaining data from various data sources. In big data analysis, data sources include databases, log files, sensor data, social media and other forms.

Various technologies and tools such as web crawlers, API interfaces and data transmission protocols can be adopted to acquire raw data from data sources. After data acquisition, preprocessing is usually required. Data preprocessing involves data cleaning, conversion, integration and standardization, so as to make the data suitable for subsequent analysis and modeling.

Data cleaning deals with outliers, missing values and duplicate records to ensure data accuracy and integrity. Common data cleaning methods include deleting outliers, filling missing values, and removing duplicate records. Data conversion includes format conversion, scale transformation, normalization and standardization, which unify data types, dimensions and distributions to facilitate subsequent analysis.

Data integration merges and consolidates data from different sources to obtain a more comprehensive dataset, which may involve data matching, conversion and standardization. Subsequent data normalization unifies naming conventions, units and coding standards to ensure consistency and intelligibility during data analysis and modeling.

Data acquisition and preprocessing are critical steps in big data analysis and play a vital role in determining the accuracy and reliability of final analysis results. Effective data acquisition and preprocessing can reduce noise, improve data quality, and provide a clean and consistent dataset for subsequent data analysis and modeling.

4.2. Geological Model Construction

Geological model construction establishes models of underground geological structures and attributes based on geological data and big data analysis technologies. Such models can provide a three-dimensional representation of the Earth’s interior, helping geologists better understand geological evolution, discover mineral resources, and conduct geological risk assessment.

Geological model construction generally consists of five steps: data acquisition and integration, data preprocessing and preparation, selection of geological modeling methods, estimation and adjustment of model parameters, as well as model verification and evaluation. Figure 3 shows the 3D reconstruction model of a complex geological structure.

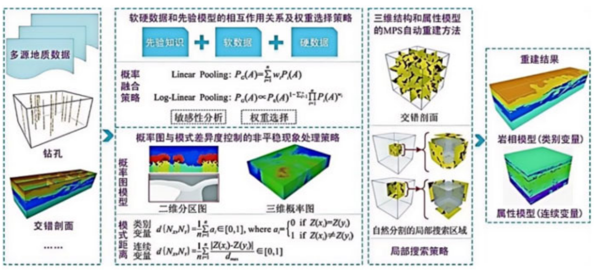

Fig.3 3D Model Reconstruction

A large amount of geological data is required for geological model construction, including geophysical data, seismic data, drilling data, and geological geochemical data. These data need to be collected from multiple sources and integrated into a unified dataset.

Before model construction, the collected data must be preprocessed and prepared, including data cleaning, conversion, integration and normalization, to guarantee data quality and consistency. Appropriate geological modeling methods are selected according to specific research objectives and data characteristics. Commonly used methods include structural interpretation, lithology identification, seismic inversion and statistical models. Each method has its own advantages and applicable scope and can be selected according to actual needs.

Model parameters are estimated and adjusted based on the collected geological data and the selected modeling method, taking into account geological structure, lithology, granularity and other parameters to accurately characterize underground geological attributes and structures. After the geological model is established, verification and evaluation are required, which can be realized by comparison with field exploration data or cross-validation methods. The verification and evaluation results help judge the reliability and accuracy of the model.

Geological model construction provides scientific basis and decision support for geological exploration, resource evaluation, environmental protection and other fields. It enables scientists to better understand the Earth’s internal structure and evolutionary history, and guides resource development and geological risk management. Big data analysis plays a key role in geological model construction, accelerating modeling efficiency and improving model accuracy and reliability.

5. Conclusion and Outlook

Previous studies have yielded essential findings and conclusions regarding the three-dimensional (3D) geological modeling method based on big data analysis, while identifying prospective development trends and potential challenges for future research.

Big data analysis possesses great application potential in geological modeling. It facilitates the understanding of geological processes, reveals the structures and attributes of subsurface geology, and contributes to the construction of highly accurate geological models. The methodologies and technologies of big data analysis are capable of processing large-scale, multi-source and multi-dimensional geological data, so as to provide comprehensive and holistic geological information. The integration of professional geological expertise and big data analytical approaches serves as an effective strategy for geological modeling. Combining traditional expert geological knowledge with machine learning, data mining and other technologies enables the effective application of big data analysis, and further improves the accuracy and reliability of geological models.

Meanwhile, future research faces several challenges. First, the scale and complexity of geological data continue to grow, posing a major challenge to the efficient processing and analysis of geological datasets. Second, data quality and reliability are core determinants of geological modeling performance, which requires the development of more efficient and automatic methods for data cleaning and quality control. In addition, the integration of geological models with cross-domain data and models, such as physical simulation models and remote sensing data, remains a vital research direction for subsequent studies.

Looking ahead, the 3D geological modeling method based on big data analysis will be further optimized and improved. With the continuous advancement of data acquisition and storage technologies, the scale and quality of geological data will be significantly enhanced. Furthermore, the rapid development of machine learning, deep learning and artificial intelligence will provide more powerful technical tools for geological modeling. Future research will focus on interdisciplinary exploration and cross-field cooperation to address complex problems and challenges in geological modeling. With the above improvements, big data analysis-based 3D geological modeling will play an increasingly critical role in geological science and relevant engineering fields.

References

[1] Zhu J X. Multi-scale and Multi-attribute Coupling Mechanism of Urban Geological 3D Modeling [D]. Chinese Academy of Geological Sciences, 2022.

[2] Li G S, Zhang P, Cai Y. Design and Implementation of Spatiotemporal Big Data Platform for Smart Taizhou [J]. Wireless Internet Technology, 2022, 19(11): 58-62.

[3] Zhang X L, Wu C L, Zhou Q, et al. 3D Geological Modeling of Manganese Deposits Based on Exploration Big Data and Data Mart [J]. Geological Science and Technology Bulletin, 2020, 39(04): 12-20.

[4] Deng C S, Er C, Guo C, et al. Study on 3D Geological Modeling of Continental Shale Gas Reservoirs in Chang 7 Member of Yan'an Area, Ordos Basin [J]. China & Foreign Energy, 2023, 28(06): 53-58.

[5] Yang X D, Chun M H, Xu S, et al. Application of Geostatistical Analysis in 3D Geological Modeling of Subsea Pipeline Routes [J]. Petroleum Engineering Construction, 2023, 49(02): 1-6+19.

[6] Li M, Sun J Y. Research on the Development of Geological Surveying and Geographic Information Industry in the Big Data Era [J]. China Mining Magazine, 2023, 32(06): 26-30.

[7] He W. Research and Application Prospect of Drilling and Completion Big Data Technology in Oil and Gas Fields [J]. Chemical Engineering Management, 2021(05): 185-186.

[8] Song Y, Gao Z J, Wang P. Cloud-based Urban Geological 3D Visualization Framework Based on Big Data Technology [J]. China Mining Magazine, 2020, 29(06): 81-86.

[9] Ping Y Q, Shen F L, Zhou N, et al. Application Analysis of Big Data Technology in Oil and Gas Geological Exploration [J]. Science and Technology Information, 2019, 17(02): 59-60.

[10] Zhu Y S, Wu H Y, Ma M. Overview of the Application of Big Data Technology in Network Security Management System in the Information Era [J]. Communications World, 2019, 26(11): 155-156.

[11] Wu Y P. Application of Big Data Technology in Oilfield Exploration, Development and Production [J]. Modern Information Technology, 2018, 2(12): 122-123+126.

[12] Wu C L, Liu G, Zhang X L, et al. Discussion on Several Issues of Geological Science Big Data and Its Utilization [J]. Chinese Science Bulletin, 2016, 61(16): 1797-1807.

[13] Qu Y. Visual Cluster Analysis of Big Data Theoretical Research in China in Recent Ten Years-Based on Bibliometric and Statistical Analysis of Five Common Literatures [J]. Journal of Library Science, 2018, 40(02): 133-138.

[14] Cui Z D, Wei T, Zhao L L, et al. Research Progress on 3D Geological Structure Modeling and Characterization for CO2 Geological Storage [J]. Quaternary Sciences, 2023, 43(02): 586-593.

[15] Sheng L, Sun Y, Yu Q T, et al. Research on 3D Geological Modeling Method Based on ArcGIS [J]. Jiangxi Building Materials, 2023(01): 145-147.

[16] He C Y, Wang Y, Wang H J, et al. 3D Geological Modeling of Jiaojia-Sanshandao Fault Zone in Eastern Jiaodong Based on Comprehensive Geophysical Constraints: Metallogenic Characteristics and Prospecting Enlightenment [J]. Geological Bulletin of China, 2022, 41(06): 936-945.

[17] Xu T, Mo F, Lin X T, et al. Research and Application of 3D Geological Modeling Method in Complex Karst Areas Based on BIM Technology [J]. Construction Technology, 2022, 51(11): 42-44+77.

[18] Lei C Y, Liu Z X, Wen H, et al. 3D Modeling of Complex Geological Bodies Constrained by Multi-source Data and Prior Knowledge [J]. Geological Review, 2022, 68(04): 1393-1411. DOI:10.16509/j.georeview.2022.06.141.

[19] Shang X F, Wang M C, Li M. Fracture Prediction and 3D Geological Modeling Based on Fault Likelihood Attribute Zonal Calibration-A Case Study of Xu 2 Member Gas Reservoir in Xinchang Gas Field, Western Sichuan Depression [J]. Journal of Northeast Petroleum University, 2022, 46(04): 62-76+5-6.

[20] Huang H M, Lu Y. Construction and Application of Real-scene 3D Model Based on Smart3D and Mofang [J]. Guangdong Water Resources and Hydropower, 2023(06): 77-81+88.

[21] Liu S, Chen J H, Wang F, et al. Construction of Real-scene 3D Model of Digital Outcrops Based on UAV Oblique Photography[J]. Geological Sciences, 2022, 57(03): 945-957.

[22] Yan L W, Tang G L, Yu X L, et al. 3D Model Construction and Reserve Estimation of Heiniudong Copper Ore Body Based on Surpac [J]. Journal of Sichuan Geology, 2021, 41(02): 338-342.

[23] Xu J C, Li C K, Chen J H. A 3D Model Construction Method Based on 3ds Max and Smart 3D [J]. Bulletin of Surveying and Mapping, 2020(11): 61-65.

[24] Xuanyu C, Shaowei P, Guanyu C. 3D model construction and accuracy analysis based on UAV tilt photogrammetry [J]. IOP Conference Series: Earth and Environmental Science, 2022, 1087(1).

[25] Jihwan J H, Jinhyeok C, Alice Y R, et al. Application of Induced Pluripotent Stem Cells for Disease Modeling and 3D Model Construction: Focus on Osteoarthritis [J]. Cells, 2021, 10(11).

[26] Wei X B, Yao X B. 3D Model Construction in an Urban Environment from Sparse LiDAR Points and Aerial Photos—a Statistical Approach [J]. GEOMATICA, 2015, 69(3).

[27] Li H G. 3D Model Construction for Deep Structure Inference of Gold Deposits Based on Three-dimensional Geochemical Exploration [J]. World Nonferrous Metals, 2020(19): 19-20.

[28] Sheng Y N, Li W T, Guan Z C, et al. Regional 3D Model Construction of Formation Pressure with Uncertainty Based on Logging Data [J]. Fault-Block Oil & Gas Field, 2021, 28(01): 89-93.