3D modeling of subsurface geo-objects with netty-cross sections in engineering geology

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Abstract

The subsurface geological condition is greatly significant for engineering field works. The geometries of underground geo-objects are generally complex and beyond the descriptive capacity of traditional 2D CAD documents. In this paper, we present a 3D modeling method to generate surface and solid models to accurately delineate and intuitively visualize the complex geometries of geo-objects. First, raw data including topographical and lithogical information were converted into a digital form and imported into a geological database. And then, the netty-cross sections were created between every two adjacent drillholes, based on which the TIN-based surface models were constructed by the constraints of lithological boundaries. And finally, solid model of each geological unit was established by spatial meshing and slice sections were built to reveal the internal lithological distribution. The proposed modeling method can be widely used in engineering geological realms, regardless of the arrangements of exploratory projects. In addition, a series of spatial analyses can be conducted in the basis of the resultant geological models.

Keywords

3D geological modeling, engineering condition, netty-cross section, solid model.

1. Introduction

Delineating the geological conditions is essential for enginnering geological designs and the following field works [1]. However, it is not an easy task when confronting complex geo-objects such as irregular magmatic intrusions, unconformable strata and/or lens-shaped deformed rocks. It makes traditional 2D CAD documents unsuitable for accurate description of such complex geological conditions[2, 3]. In the last decade, 3D modeling has been developed rapidly in a wide range of geological realms[4], providing assistance for resources exploration[5], hydrogeological analysis[6] and engineering geology[7, 8].

Numerous modeling methods for addressing practically geological problem have been fully developed. The prevailing modeling methods can be commonly subdivided into several categories based on different data sources, such as modeling based on cross sections[9], geological maps[4] and geophysical data[10]. 3D modeling based on cross sections is a major method applying in engineering geological modeling for its simple workflow and convenient operation[11]. Nevertheless, the drillholes are generally not arranged within a straight lines in the engineering investigation, making it hard or impossible to generate a consective cross section on the basis of the drillholes, which limits the application of 3D modeling method on engineering geology.

In this paper, we present an improved modeling framework that generates 3D geological models by netty-cross sections. Taking a case study from practical engineering field works, we show how the 3D geological modeling should smartly utilize the raw data and depict the complexity of geo-objects as precisely as possible.

2. Data processing

Geological modeling is essentially a process converting low-dimensional data into high-dimensional models. The raw data collected from field works are usually in sparse, manual form and have to be transformed to an uniform, digital form so as to be used for subsequent modeling. Two types of data have to be collected and processed in this contribution: Digital Elevation Model (DEM) and drillhole logs.

DEM describes the topographical conditions of the study area. It is often constructed on the basis of large-scale topographical maps. However, DEM has to be refined when there exist drillholes in the study area. The collars of drillholes are located on the ground surface and their coordinates are accurately measured, thus, the DEM must be adjusted in accordance with the exact location of drillhole collars (Fig. 1a).

Drillhole log generally comprises project information and lithological logging information. These data must be involved in a geological database which can be directly used in modeling workflow. The database of drillhole is consist of two chain tables in this case study, including table of drillhole collar and table of lithological interval (see their structures in Table 1). The table of drillhole collar contains the 3D coordinates of drillholes location and the drilling depth, while the table of lithological interval concerns the lithological subdivision of drill core. These chain tables are connected by the linking of the term Drillhole ID. Once the database is set up, the lithological units in this area, including miscellaneous fill, sandstone, metamorphic sandstone and granite, can be intuitively exhibited in a virtual 3D space (Fig. 1b).

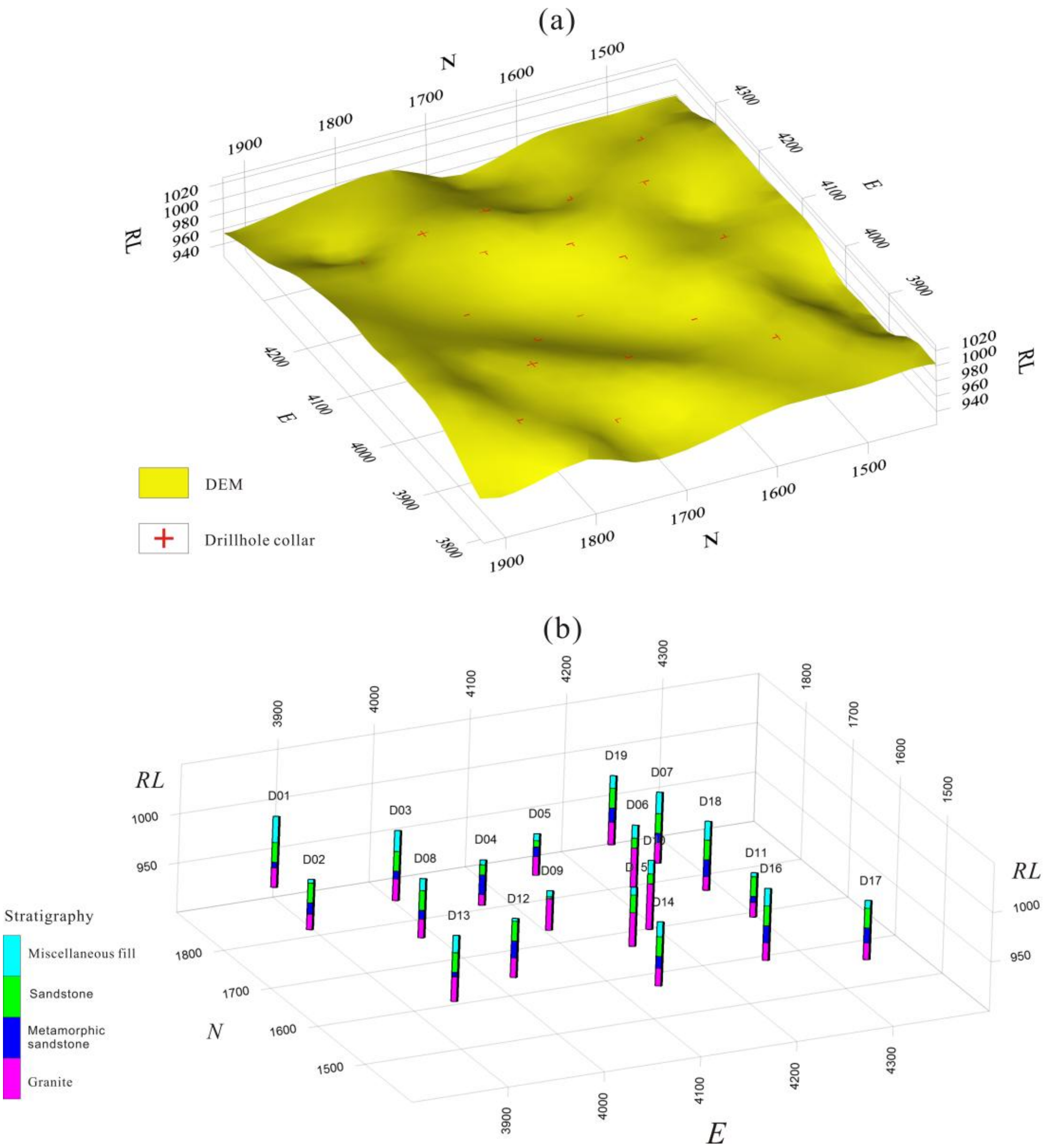
Table 1 Data structure of drillhole database

Chain table	Terms	Content
Drillhole collar	Drillhole ID	numbers of drillholes
Drillhole collar	East coordinate	east coordinate of drillhole collar
Drillhole collar	North coordinate	north coordinate of drillhole collar
Drillhole collar	RL coordinate	elevation of drillhole collar
Drillhole collar	Depth	drilling depth
Lithological logging	Drillhole ID	numbers of drillholes
Lithological logging	From	the distance between starting point of each lithological interval and drillhole collar
Lithological logging	To	the distance between ending point of each lithological interval and drillhole collar
Lithological logging	Lithology	Lithological descriptions

3. 3D geological modeling

3.1 Generating netty-cross sections

The traditional modeling method based on cross section needs to create some orientated cross sections which contain enough drillholes. However, the drillholes implemented in engineering geological field works are often sparse without a specific orientation, leading to limited application of cross section-modeling. To overcome this drawback, we generated a series of cross sections which formed a net model. More specifically, we generated a netty-cross section between every two adjacent



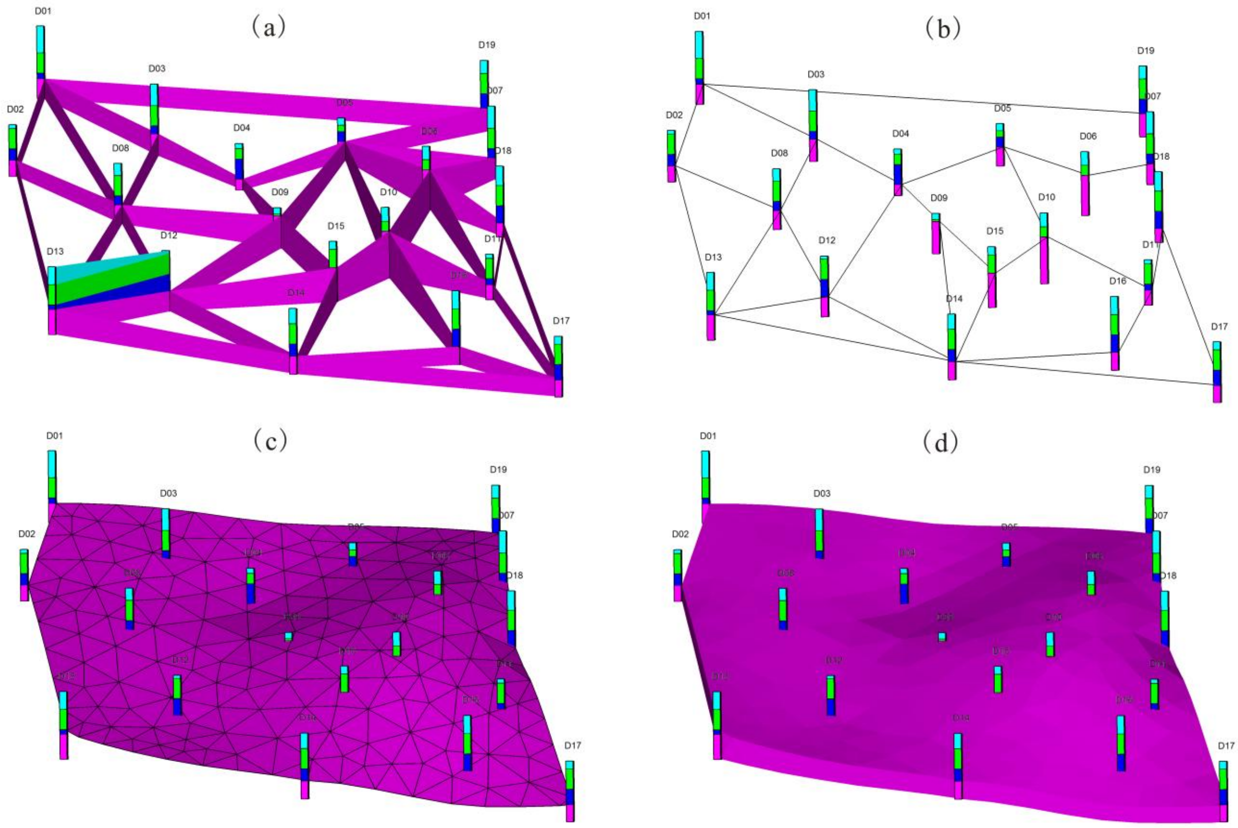
(a) DEM constrained by drillhole collar; (b) stratigraphical subdivision of each drillhole.

Fig. 1 Resultant model of data processing

drillholes, e.g., D12 and D13 (Fig. 2a). A closed polygon was created to link the same lithological interval of these two drillholes. In this way, each netty-cross section can reflect the local lithological distribution between two drillholes. By combination of all the netty-cross sections, a framework model was constructed, confining the vertical borders of an independent lithological unit (see granite borders in Fig. 2a).

3.2 TIN-based surface construction

Triangular Irregular Network (TIN) was chosen in our modeling because it can offer modeler a high degree of flexibility when depicting complex geological surfaces. The horizontal boundaries such as top surface and bottom surface were reconstructed by constrained TIN modeling. Firstly, the top boundary lines were extracted from netty-cross sections (Fig. 2b). These boundaries were imported as raw data and also linear constraints in the whole modeling process. Secondly, TIN model was created by inserting new nodes whose locations were interpolated under the law of Delaunay Triangularity[12] (Fig. 2c). This law forced the interpolated nodes to establish equilateral triangles as much as possible, which results in a naturally smooth TIN model. The bottom surface of granite was created in the same way. Thirdly and finally, the horizontal surfaces and vertical surfaces were combined together to build a closed surface model that delineates the geometrical shape of granite (Fig. 2d).



(a) Generating netty-cross section; (b) exacting top boundary of granite; (c) TIN interpolation; (d) surface optimizing and model output.

Fig. 2 Workflow of TIN-based surface modeling

3.3 Solid models and spatial analysis

TIN model is a surface-representative model which can well reflect the complex geometries of geo-objects, but it is limited in revealing the internal lithological variation for the lithological information in the inner space is barren. In this study we generate solid models to delineate the internal lithological distribution. The inner space within the closed TIN model was spatially meshed with thoudsands of tetrahedrons. Three solid models were created in the study area, representing the responding lithological units which are miscellaneous fill, sandstone and granite (Fig. 3a). In order to better visualize the internal lithological distribution, five slice sections along E-W and N-S directions were created. In these slice sections, the lithological subdivisions show some interesting variation. The intruded granite has a convex shape in the centre of the study area, while it exhibits a more sharply inclining trend along the E-W orientation than that along S-N orientation (Fig. 3b). The thickness of sandstone varies frequently at different locations, which is controlled by both topographical conditions and convex degree of granite intrusion. In the centre of the study area, the sandstone almost thins out, attributed to the obvious concave of ground surface and the remarkable convex of granite intrusion (Fig. 3b).

4. Conclusions and future work

An improved method for constructing 3D model in engineering geology was presented in this paper. The DEM and geological database of drillholes were established by data processing. The netty-cross sections were created to accurately represent the distribution and variation of lithological conditions between every two adjacent drillholes. The surface models based on TIN were built to depict

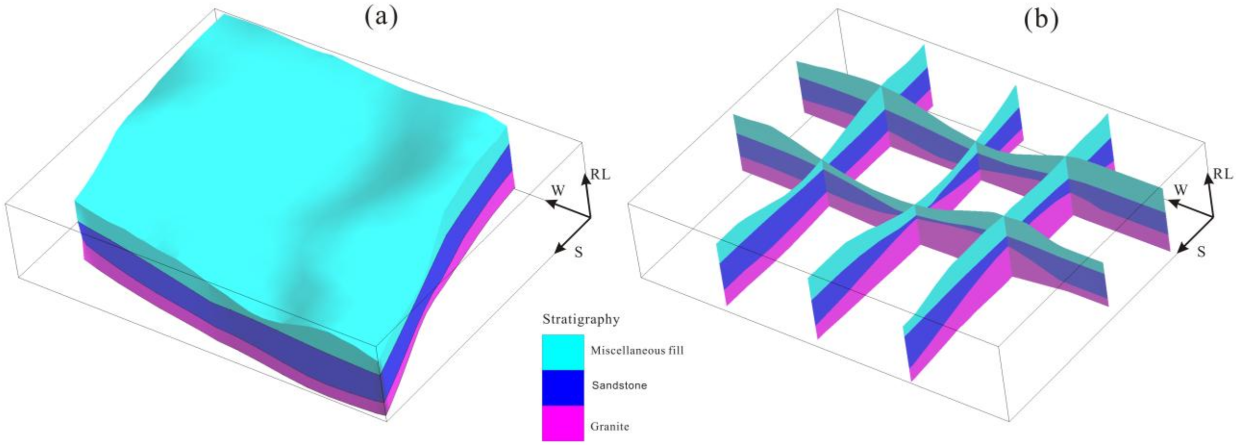


Fig. 3 Solid model (a) and slice section (b) of lithological units in the study area.

horizontal geometries of each independent geological unit. The solid model and slice sections were generated to reveal the internal distribution and variation of lithology. By the combination of above models, the spatial analysis concerning geometrical shapes and mutual relations of geo-objects was conducted.

The proposed method can be widely applied to the engineering geological works regardless of the arrangement of exploratory projects. However, the subsurface geology is extraordinarily complex and therefore requires a comprehensive means to verify the uncertainty of modeling results. In future work, we plan to use multi-sources data including cross sections, drillholes, tunnels and geophysical data to construct the underground geo-objects. In addition, the quantitative spatial analysis based on modeling results will be introduced.

Acknowledgments

The research leading to this paper was supported by the Startup Foundation of Jiangxi University of Science and Technology (grant no. jxxjbs15002).

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