PRELIMINARY STUDY ON GEOMETRIC MODELING OF GEOLOGIC BODY①

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ABSTRACT At the first time, the concept and the techniques of geometric modeling of geologic body were proposed. The three-dimensional geologic bodies can be classified into three types: point-like, line-like and plane-like geologic bodies. With geometric modeling techniques and methods, the models for geometric modeling of various geologic bodies have been derived and their attribute extensions were also dealt with, which provide a new way for describing complex geologic bodies with computer language.

Key words geologic body geometeric modeling computer-aided design

1 INTRODUCTION

Modeling and representation of geologic bodies is an essential topic of various research fields of earth science such as structural geology, mineral geology, prediction of resources, geometry of orebody, prospecting and mining. The studies on the description of geologic body[1-6] have been attempted in different aspects by many geologists and researchers, but a good solution has still not been achieved.

The modeling and computer representation of geologic body have been completely achieved by the authors and research group using computer aided geometric modeling and other techniques after researching and experimenting for several years. As a result of the achievment, the authors also solved the automated generating and plotting of geology-survey maps which were a difficult topic with no progress for long[5, 6].

2 GEOLOGIC BODY AND GEOMETRIC MODELING

2.1 Geologic body

Geologic body is a natural object with spacial occupation formed by geologic agent in geologic epochs, which is an irregular object with natural and arbitrary shape, and can be classified into orebody, structure, stratum and others by composition.

To investigate geologic bodies, we frequently get the data of limitation lines and compositions of geologic bodies by means of geological engineering control and geological mapping, and describe geologic bodies and their spatial distribution and assemblage by different geologic maps (e.g. generalized geologic map, exploration section map, level geologic map). To study geologic bodies more proficiently, many scientists also quantitatively describe geologic bodies in different models such as model of mineral deposit[4], mathematical characteristics of geologic body[1], and model of spatial distribution. However, these models cannot describe geologic bodies as completely and intuitively as geologic maps.

Geologic body is a three-dimensional object. We are apt to or tend to describe the real 3-dimensional object by a series of profiles of the object (e.g. exploration sections, level plans). Acturally, a series of parallel profiles can objectively and perfectly describe geologic bodies in 3-dimensional space because we can acquire the complete 3-dimensional model if the 2-dimensioanl representation is valid.

By its shape the 2-dimensional geologic

① Received Jan. 25, 1997; accepted Nov. 18, 1997

body can be classified into three types: (1) point-like geologic body, e.g. geologic outcrop spot; (2) linear geologic body, e.g. fault; (3) planar geologic body, e.g. orebody, rock mass.

In our research, for the uniformity of the description of various geologic bodies and engineerings, we can recognize a geologic engineering as a geologic body with special attributes.

2.2 Geometric modeling

Geometric modeling is the method and technique to define the shape and geometric characteristics of an object. Geometric modeling provides analytic and quantitative models and techniques for the descriptions of real objects and processes. Geometric modeling can effectively carry out the mathematical representation, design and rendering of a real object.

Geometric modeling can construct and represent an object in many ways which mainly are graph-base models, boolean models, parametric representation, cell decomposition representation, constructive solid geometry, boundary representation and curve frame representation.

2.3 Geometric modeling of geologic body

Geologic body is also the object in space, but its shape is not regular. Based on the raw data of geologic body, by means of geometric modeling we can carry out mathematical representation, design and rendering of geologic body, which is defined as geometric modeling of geologic body (GMGB).

Because geologic body is a shape-irregular object, we should use general construction and representation techniques (e.g. graph-based models, boolean models) to carry out geometric modeling of geologic body and represent it, which are based on the applicable parametric geometry to shape-irregular object (e.g. parametric representation of natural curve). Meanwhile, we can describe the attribute characteristics of geologic body by means of their attribute data (e.g. geologic body's type and composition), which may be perfectly combined with the geometric modeling models of geologic body to accomplish the extension of geometric modeling of geologic body. Therefore geometric modeling of geologic body is actually the attribute-extension geometric modeling of shape-irregular object. In computer, we will store the geometric data, topologic data and attribute data of geologic bodies on extended relation model.

3 MODEL OF GEOMETRIC MODELING OF GEOLOGIC BODY

Geologic body in 2-dimensional space can be classified, by shape, into three types: point-like geologic body, linear geologic body and planar geologic body. The constrution of the geometric modeling models of geologic body can be finished in 2 aspects: (1) the geologic body geometric models (the object pure-geometry information such as co-ordianates, equations, and the topologic and linking information among the object elements); (2) the geologic body attribute extension.

3.1 Point-like geologic body

3.1.1 Geometric model of point

A point-like geologic body in 2-dimensional space can be represented geometrically by a 2-dimensional co-ordinate point (node) as follows

$$P = (x, y) \tag{1}$$

3.1.2 Attribute extension

A point-like geologic body owns its attribute characteristics which may include several attribute items (e.g. point name, element contents, etc.). The point-like geologic body's model P_g by attribute extension of P can be defined as

$$P_g = (P, a) \tag{2}$$

3.2 Linear geologic body

3.2.1 Geometric model of edge

The polyline composed of a series of sorted nodes $P_j (j = 1, 2, \cdots, n)$ is called as an edge or an arc. An edge e can be described as

$$e = \{P_j\} \quad j = 1, 2, \cdots, n \tag{3}$$

3.2.2 Geometric model of linear geologic body

(1) Regular linear geologic body

A simple object like a drill hole, a prospecting trench and so on actually is composed of one or more edges (polylines) with one's tail linked to another's head, i.e., a regular linear geologic body can be described as

$$L = \{e_i\} \quad i = 1, 2, \cdots, m \qquad (4)$$

(2) Irregular linear geologic body

A large number of linear geologic bodies are shape-irregular and take natural curve shapes such as faults, boundaries of rock beds and rock masses. There are engineering points or observation points located at bent or hinge positions to control the geologic bodies, but no other control points between the engineering or observation points. Therefore, it is unfit for edge models with regular linear equation to represent the irregular linear geologic bodies, which need to be described by tertiary parametric splines with natural smoothness (C^2 continuance) as follows:

$$L = \{S_i\} \quad i = 1, 2, \cdots, m \qquad (5)$$

where S_i is tertiary parametric spline curve:

$$S_i = \{P_1, P_2, \cdots, P_n, B_1, B_2, \cdots, B_{n-1}\} \qquad (6)$$

In the above formula, B_1, B_2, $\cdots$, B_{n-1} are subcurve coefficients, and B_j (B_{j0}, B_{j1}, B_{j2}, B_{j3}) is the coefficient of the jth subcurve, the formula of which is

$$\left.\begin{aligned} B_{j0} &= P_j \\ B_{j1} &= P_j' \\ B_{j2} &= 3(P_{j+1} - P_j)/l_j^2 - (P_{j+1}' + 2P_j')/l_j \\ B_{j3} &= -2(P_{j+1} - P_j)/l_j^3 + (P_{j+1}' + P_j')/l_j^2 \end{aligned}\right| \qquad (7)$$

where $l_j = [(x_{j+1} - x_j)^2 + (y_{j+1} - y_j)^2]^{1/2}$ and P_j' ($j = 1, 2, \cdots, n$) is the solution of the following equation group:

$$\left.\begin{aligned} & 2P_1' + \mu_1 P_2' = C_1 \\ & \lambda_j P_{j-1}' + 2P_j' + \mu_j P_{j+1}' = C_j \\ & j = 1, 2, \cdots, n-1 \\ & \lambda_n P_{n-1}' + 2P_n' = C_n \end{aligned}\right| \qquad (8)$$

where $\mu_1 = \lambda_n = 1$, $C_1 = 3(P_2 - P_1)/l_1$, $C_n = 3(P_n - P_{n-1})/l_{n-1}$, $\lambda_j = l_j/(l_j + l_{j-1})$, $\mu_j = 1 - \lambda_j$

From the above formulae, the tertiary parametric spline equation of the jth subcurve(segment) of the curve S_i:

$$P(t) = B_{j0} + B_{j1}t + B_{j2}t^2 + B_{j3}t^3$$

$$t \in [0, l_j] \quad j = 1, 2, \cdots, n-1 \qquad (9)$$

Practically, we can transform curve S_i into edge e_i by spline interpolation, but the edge e_i includes a large number of interpolation nodes besides the nodes belonging to the curve S_i. According to this, the representation Eqn. (5) of the irregular linear geologic bodies can be simplified as

$$L = \{e_i\} \quad i = 1, 2, \cdots, m \qquad (10)$$

3.2.3 Attribute extension

A linear geologic body bears its attribute characteristic which may include several attribute items(e. g. fault name). The linear geologic body's model L_g by attribute extension of L can be defined as

$$L_g = (L, a) \qquad (11)$$

3.3 Planar geologic body

3.3.1 Geometric model

A planar geologic body such as orebody, rock mass appears an enclosed polyline in shape, which is composed of a series of curve segments with one's tail linked to another's head. As related above, a curve segment can be described by edge model Eqn. (3), no matter it is regular or irregular. Therefore, a planar geologic body can be represented geometrically by the model

$$F = \{e_i\} \quad i = 1, 2, \cdots, m \qquad (12)$$

where the start node of e_1 and the end node of e_m are the same node (called as shared node).

3.3.2 Attribute extension

A planar geologic body has its attribute characteristics which may include several attribute items(e. g. name, area, etc.) . The planar geologic body's model F_g after attribute extension can be defined as

$$F_g = (F, a) \qquad (13)$$

3.4 Complex geologic body

The three kinds of geologic bodies discussed above are simple and undivided. In fact, a big complex geologic body is usually composed of some small geologic bodies. For example, an iron ore belt is a complex planar geologic body bacause it is composed of several ore blocks which are planar geologic bodies. A complex planar geologic body may be composed of simple point-like, linear and planar geologic bodies and complex geologic bodies, and similarly a complex linear or planar geologic body may be composed of simple point, linear and planar geologic bodies and complex geologic bodies. So we can define the geometric model of a complex geologic body as

$$C = \{G_{gi}\} \quad i = 1, 2, \cdots, m \qquad (14)$$

where G_{gi} is a daughter geologic body composing the complex geologic body C.

A complex geologic body has its attribute characteristic just as a simple one. Some attributes, e. g. area, element content, of complex geologic bodies can be derived from their daughter bodies. The model C_g by attribute extension of C is as follows

$$C_g = \{C, a\} \qquad (15)$$

3.5 Topological structure of geologic body

The topological structures of geologic bodies describe the spatial relations of geologic bodies. The spatial relations are expressed mainly by two kinds of topological relations, i. e. association relations and adjacency relations.

Association topological relations describe the interactive relations of nodes, edges and faces, which can be divided into up-to-down(face-edge-node) and down-to-up association relations. The up-to-down relations present the composition of geologic bodies (point, linear, planar geologic bodies), which are just the topologic relations that the geologic models above express(obvious or direct expression). It is apparent that the down-to-up topological relations can be derived from the up-to-down relations.

The adjacency topological relations can be directly derived from the association relations. For instance, two adjacent planar geologic bodies bear a common edge(shared edge), so we can infer if two planar geological bodies are adjacent by calculating if they share a common edge.

Based on the above relations, it can be concluded that the models of geologic bodies listed above describe not only the pure geometric and attribute information but also the topological structures of geologic bodies.

3.6 Geometric analysis and modeling operation of geologic body

All geologic bodies constructed by geometric modeling sometimes need to do geometric operation to build new geologic bodies. For instance, in an opencast, geologists, surveyors and miners must often calculate and plot the blasted orebodies, which are actually the overlayed area of the blasted segment and the ore bodies.

Between geologic bodies G_a and G_b, there are mainly union, intersection and subtraction operations, by which we can construct a new geologic body G_c as follows

(1) Union operation: $G_c = G_a \cup G_b$

(2) Intersection operation: $G_c = G_a \cap G_b$

(3) Subtraction operation: $G_c = G_a - G_b$

The calculation formulae of the operations are different for different types of geologic bodies. The operations of point-like and linear geologic bodies can be done through containment, intersection and other calculations. When two geologic bodies are planar, we should adopt the polygon caculation formulae to do the operations.

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(Edited by He Xuefeng)