Development of Prototype System for Geologic Surface Estimation on the Web

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ABSTRACT

The purpose of the present study is to develop a surface estimation system that enables users to determine an optimal geologic surface on the Web using various geologic information. The prototype system has been developed to estimate a geologic surface using two kinds of field survey data on the Web. The procedures for surface estimation using this system are as follows: 1) upload field survey data, 2) generate distribution map of the uploaded data, 3) determine an optimal geologic surface, 4) generate a DEM (Digital Elevation Models) for estimated optimal surface and 5) download the result. The main base data are elevation data observed in the field survey. The strike-dip data are also available. The optimal geologic surface is determined based on smoothing algorithm with bi-cubic B-spline function. There are three kinds of output data: 1) mathematical function that represents the optimal geologic surface, 2) evaluation parameters for smoothness of the surface and goodness of fit and 3) DEMs with arbitrary size of grids. In this paper, we described the detail of the system and showed two examples of surface estimation.

1. INTRODUCTION

Geologic information is quite useful in the analyses of the subsurface structure. Especially geologic point data, such as borehole data and concentration data, play a important role in understanding a condition in the ground. However, since these data are observed irregularly in the field survey, it is hard to understand the condition in the ground directly from the observation data.

In order to utilize the geologic point data in practical analyses, a surface estimation such as the generation of DEM (Digital Elevation Model) is usually performed. A considerable number of studies have been conducted on the algorithms for surface estimation in the field of geology as well as in many other fields so far. In addition, various systems have been developed based on those algorithms. However, most of systems work in stand-alone mode. It means that the user needs to make a suitable environment for installing the systems on their own PC. This becomes a big obstacle to utilization of the geologic point data as well as to diffusion of the systems.

Recently the concern with the management of geologic information on the Web has been growing. However, most of management systems just has the capability of storing the data. There are very few systems that have the capability of processing the geologic information on the Web. The Web-base processing system for geologic information enables us to perform the surface estimation without preparing a new PC environment. Moreover it leads to a higher utilization of the geologic information over the Internet. In this study, in order to encourage the use of geologic information, especially the use of geologic point data, we have developed a prototype system for geologic surface estimation based on the Web.

2. ALGORITHM FOR SURFACE ESTIMATION

An algorithm proposed by Nonogaki *et al.* (2008) is adopted to estimate a geologic surface from the observation data in the field survey. As the purpose of this paper is concerned, it is not necessary to discuss the algorithm in detail. In this chapter, we describe only important parts of the algorithm, which are required for carrying out the system.

2.1 Observation data available in surface estimation

Two types of observation data are used as constraints to determine the optimal geologic surface. One is elevation data that constrain the height of the surface. The other is strike-dip data that constrain the trend of the surface. The elevation data can be further classified into following two types: equality elevation data and inequality elevation data. As for the difference between equality-inequality elevation data, see Nonogaki *et al.* (2008).

2.2 Geologic surface

Suppose that a geologic surface can be expressed in $z = f(x, y)$. In here, we use "Bi-cubic B-spline function" to express the surface. Let $\Omega = \Omega_x \times \Omega_y = [x_{\min}, x_{\max}] \times [y_{\min}, y_{\max}]$ be a rectangular domain in x-y plane (Figure 1). Dividing the domain Ω into $M_x \times M_y$ sections, the surface in the domain Ω can be expressed in a quadratic form:

$$f(x, y) = \sum_{i=1}^{M_x+3} \sum_{j=1}^{M_y+3} c_{ij}\, N_i(x)\, N_j(y) \tag{1}$$

where $N_i(x)$ and $N_j(y)$ are normalized cubic B-spline bases with respect to x and y respectively. c_{ij} are the constants for the products $N_i(x)N_j(y)$.

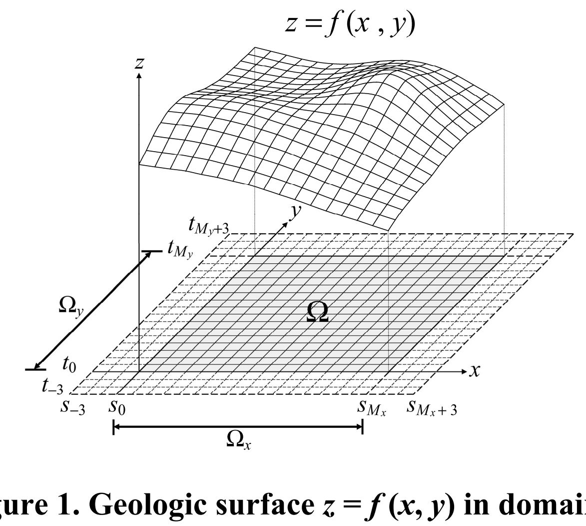

Figure 1. Geologic surface $z = f(x, y)$ in domain Ω.

2.3 Determination of optimal surface

There may be many feasible surfaces that satisfy the equality-inequality elevation data and strike-dip data. We assume that an optimal surface must be the smoothest one among the feasible surfaces. Based on the exterior penalty function method, we find the surface that minimizes an augmented objective function:

$$Q(f) = \{m_1 J_1(f) + m_2 J_2(f)\} + \alpha \{R_H(f) + \gamma R_D(f)\} \quad (2)$$

where $J_1(f)$ and $J_2(f)$ are functional that evaluate the flatness and smoothness of the surface respectively. $R_H(f)$ and $R_D(f)$ are functional that evaluate the fitness of good for elevation data and strike-dip data respectively. m_1, m_2, α and γ are parameters that adjust not only weight balances but also dimensions between four functional. As for the detail of the functional and parameters, see Nonogaki *et al.* (2008).

The optimal surface is provided in a form of bi-cubic B-spline function (equation (1)). This surface has the continuity up to partial derivatives of second order. Thus, it is possible to calculate a value of the surface on any point within the domain Ω. Consequently, we can generate a DEM with arbitrary size of grids in arbitrary domain within Ω.

3. PROTOTYPE SYSTEM

The prototype system for geologic surface estimation has been developed based on FOSS (Free and Open Source Software). The main aim of this system is to generate the DEMs for geologic surfaces using geologic point data. In this chapter, we describe the system configuration and the procedures of surface estimation, and show two examples of use of this system.

3.1 System configuration

The system works on LINUX OS environment. It consists of Web server, mapping tool and some other software. Table 1 shows the components making up the prototype system.

Table 1. Components of the prototype system.

Items	Name	Version
Operating System	CentOS	5.4 (kernel 2.6.18)
Web Server	Apache	2.2.3
Mapping Tool	GMT	4.5.3
Other Software	PHP	5.1.6
	Python	2.4.3
	JAVA	1.6.0

3.2 Procedures of a surface estimation

A basic authentication is needed to access the system. Since all operations can be done through the Web browser such as Internet Explorer or Mozilla Fire Fox, there is no need to prepare any special environments on our own PC. There are five steps to perform a surface estimation and to obtain a DEM for the estimated geologic surface as follows.

<u>Step1: Upload the field survey data</u>

First of all, we have to upload a field survey data into the system. Elevation data and strike-dip data are available as stated above. File formats for each data are shown in the browser screen (Figure 2(a)).

<u>Step2: Generate a distribution map</u>

In this step, in order to obtain the criteria for surface estimation, we generate a distribution map of the field survey data. With the help of a distribution range of the data, define the following information: (i) the geographical coordinates of the map edge, (ii) intervals of grid lines that will be drawn on the map and (iii) horizontal and vertical map size in cm. File name for the distribution map is automatically given by the system (Figure 2(b)).

<u>Step3: Determine an optimal surface</u>

In this step, we define a set of parameters for surface estimation. With the help of the distribution map, define the following information: (i) calculation range, (ii) number of small cells inside the calculation range (number of sections inside domain Ω: M_x, M_y) and (iii) some other parameters. The penalty gamma is available when strike-dip data are uploaded. There are two kinds of output files. One is for mathematical function of the optimal geologic surface. The other is for various information about operated estimation, such as evaluation results for smoothness of the surface and goodness of fit. File names are automatically given as well as the distribution map (Figure 2(c)).

<u>Step4: Generate a DEM for the optimal geologic surface</u>

In this step, we check the estimation result and generate a DEM for the optimal geologic surface. When the system finishes the estimated calculation, it shows not only the evaluation results of the functional but also the contour map of the optimal surface on the browser screen. Both can be saved as PS format and PNG format. With the help of these two data, we determine whether the result is feasible or not. After obtaining the acceptable result, define the following information: (i) file name and file format for DEM, (ii) output range and (iii) number of grids. The output range must be inside calculation range. There are two types of DEM formats. One is "Horizon Grid" format. The other is "GRASS ASCII" format ((Figure 2(d) and (e)).

<u>Step5:Download the result</u>

In this step, we just save the DEM in a specified file after confirming the parameters of DEM generation (Figure 2(f)).

3.3 Examples

Figure 2 shows an example of operation screens during a surface estimation with a simple data set of elevation data listed in table 5.11 by Davis (1986). Figure 3 shows an example of the application of the geologic surfaces (DEMs) derived from the prototype system into three dimensional geologic modeling with GRASS GIS.

Figure 2. Example of operation screens. (a) data upload screen, (b) distribution map generation screen, (c) optimal determination screen, (d) DEM generation screen, (e) functional evaluation screen and (f) data output screen.

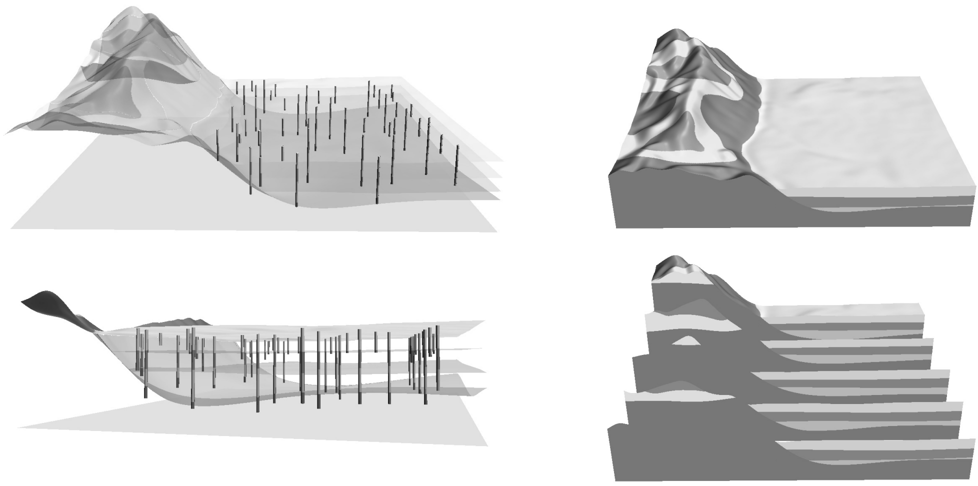

Figure 3. Application of the estimated geologic surfaces to three dimensional geologic modeling based on borehole data with GRASS GIS.

4. CONCLUTIONS

The prototype system has been developed to estimate a geologic surface on the Web. The system enables us to generate DEMs for the geologic surfaces without preparing any new PC environments. The DEMs can be saved as not only Horizon format but also GRASS ASCII format, a format supported by GDAL (Geospatial Data Abstraction Library). Therefore, it is possible to apply the geologic surfaces derived from the prototype system into various GISs or Web-GISs (See Figure 3).

Recently, there are several Web-based systems for three dimensional geologic modeling (e.g. Nemoto *et al.*, 2003; Masumoto *et al.*, 2008). A further direction of this study will be to interoperate our system with those systems. This encourages the use of geologic information over the Internet. An immediate goal is to manage the field survey using PostGIS, to implement a three dimensional visualization function of the surface and to increase the available types of output format.

5. ACKNOWLEDGEMENT

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