AN INTERPOLATION METHOD FOR CONTINENTAL DEM GENERATION USING SMALL SCALE CONTOUR MAPS

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Abstract:

A continental DEM (Digital Elevation Model) is indispensable to solve global environmental problems. For continental DEM generation, an interpolation method using contour map becomes very helpful. We developed new reliable interpolation method which based on an intermediate contour line derivation. The intermediate contour line can be drawn by using a buffering method. The buffering is a very popular technique in GIS (Geographic Information System), which can be calculated distance from any points, vectors or polygons. So, it can apply to intermediate contour line derivation

This paper presents a methodology of buffering method. And the results were compared with existing methods. Items for comparison are elevation, inclination, aspect, stream pattern and slope stability. The developed method gave the best results in all items.

A relationship between a contour interval and an accuracy of generated DEM was concluded. The results showed a ratio of pixels of contour line in the whole raster map image must be more than 20%.

1. INTRODUCTION

A continental DEM (Digital Elevation Model) is indispensable to solve global environmental problems. NGDC, NOAA offers global land one-km base elevation (GLOBE). Its current version 0.1 is covering about 60% of the Earth's land surface. So, we must generate DEM ourselves sometime.

Nowadays, there are many methods of DEM generation such as a stereo-matching from aerial photograph or satellite image, an interferemetry from stereo SAR data and an interpolation of topographic maps. For regional DEM or continental DEM generation, the interpolation method using a small scale contour map becomes very helpful. However, almost existing methods of the interpolation are intended for a large scale contour map. A mall scale contour maps have some

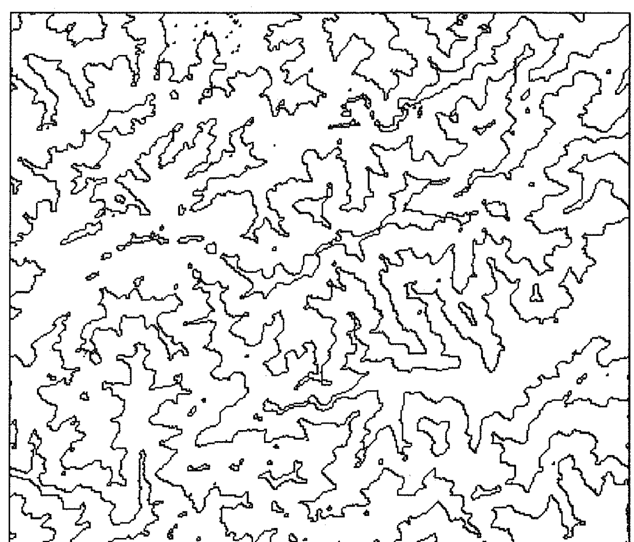

Figure 1 Contour line map

problems: a shape of contour line is often much different from the neighbor contour line; and there are very few information of contour in low land area (Figure 1).

By the way, DEM can be divided into two models: Raster type; and Vector type. A represented vector type DEM is TIN (Triangulated Irregular Network) model. This model is supported by almost GIS software. An accuracy of this model depends on network condition. The triangle sometime rejects detail of complicated contour line. So, an accuracy of raster type DEM is higher than TIN. Therefore, an objective DEM in this study is selected raster type.

Generally, an interpolation of contour line is calculated pixel by pixel for raster type DEM. A profile or a window is usually used for the interpolation. However, when we use a small scale contour map, generated DEM from those methods have not enough accuracy. So, we developed new method which is based on intermediate contour line derivation. And an efficiency of the developed method was discussed by comparing with existing methods.

For evaluation, comparison item is usually used only elevation. However, DEM is applied to many analysis such as hill shading, run off analysis, slope stability analysis and so on. Those applications require a total balance which is combination of elevation, inclination and slope aspect. Therefore we tried to evaluate on many items. For example elevation, inclination, slope aspect, undulation, stream pattern and slope stability was used. Finally, a relationship between contour line interval and accuracy was concluded. This information will be very important to generate DEM from a contour map.

2. EXISTING INTERPOLATIONS

The most popular method of the interpolation is using a profile which include target pixel. In this paper, this method is called *"profile method"*. An elevation of the target pixel can be estimated by curve fitting from crossing points of contour line along the profile. Linear equation, polynomial equation, second order equation or Spline function is used as curve fitting equation. Figure 2 shows a shaded image of generated DEM by Spline function from a test contour line map (Figure 1). The contour line interval was spread purposely in order to see reliability of the result. In this image, there are many radiated noises which are along calculated profile. Searching the most suitable direction of profile is difficult in this method.

Another popular method of the interpolation is using a window which a target pixel is located on the center. In this paper, this method is called *"window method"*. Consisted pixels of contour lines in the window are used as random points. An elevation of the target pixel can be estimated by weighted mean calculation. Figure 3 shows a shaded image of generated DEM from

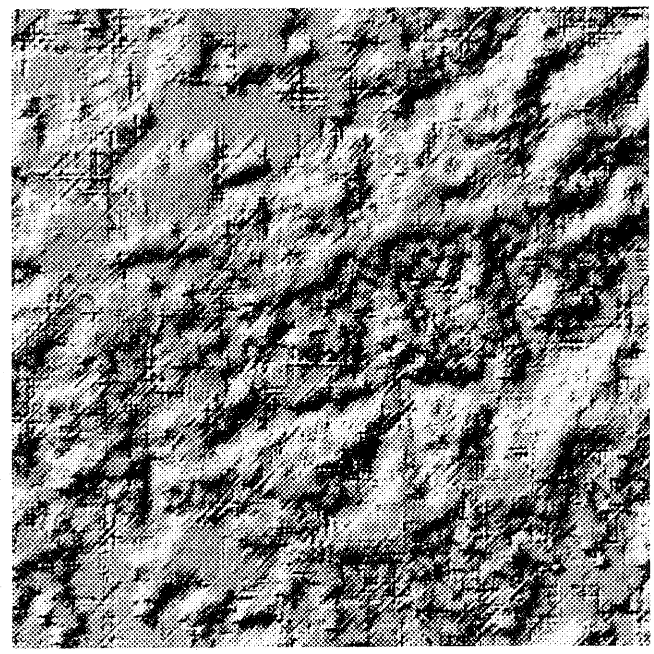

Figure 2 Shaded DEM from Profile method

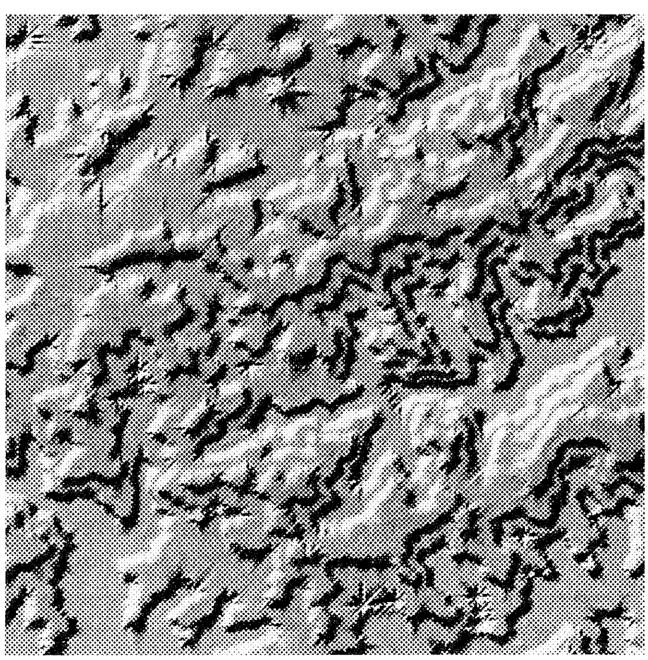

Figure 3 Shaded DEM from Window method

the previous contour line map (Figure 1). In this image, there are steep slopes along the contour lines. And other area become flat. In this method, definition of weight and window size is difficult. And in case of complicated contour line, a detail can't be represented.

Therefore, more reliable method of the interpolation should be developed when rough contour line map is used.

3. DEVELOPED INTERPOLATION

We attempted to develop a new method using buffering which is one of GIS techniques. In this paper, this method is called *"buffering method"*. The buffering method is not calculate pixel by pixel, which is based on an intermediate contour line derivation. The intermediate contour line can be drawn by using buffering image. Buffering can extracts distance from any points, vectors or polygons. In raster type data, distance is given to each pixel as an attribute. Figure 4 shows illustration of intermediate contour line derivation. If we have 100m and 200m contour line in the image, the distance from each contour line can be set to whole pixels. For example, gray level shows distance from contour line. Therefore, the intermediate contour line is located on same distance from each contour line. Same distance points from each contour line compose intermediate contour line. On the other hand, we have another easy process to draw intermediate contour line. It is based on making fat contour line. Every contour line is made fat by one pixel at a same time until whole pixels are fill with contour line value. That is one application of Morphology (Serra, 1988). Then, boundaries of the contour line becomes intermediate contour line. After that, newer intermediate contour line can be drawn from previous intermediate contour line and original contour line. By iteration of this process, intermediate contour line should be drawn until whole pixels are fill with contour line.

The intermediate contour line derivation could be applied in case of enclosed area with different contour line. By the way, other area which enclosed with same contour line must be calculated by different method. Such area is corresponded to valley or ridge area. A buffering can also apply in such area. Figure 5 shows illustration of buffering result in enclosed area with 200m contour line. The buffering result can be seen like contour line itself. Therefore, same elevation can be given to same buffering pixels. In

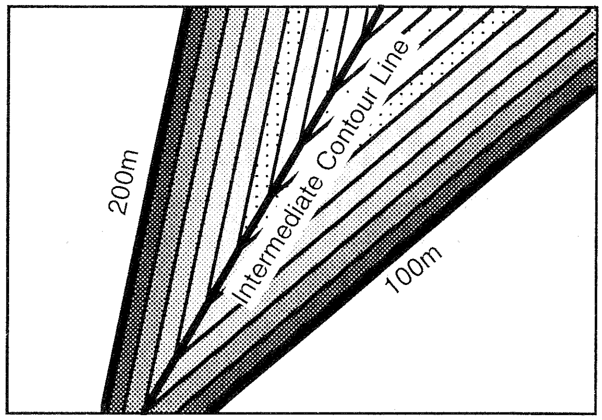

Figure 4 Illustration of intermediate contour line generation in case of enclosed area with different contour line

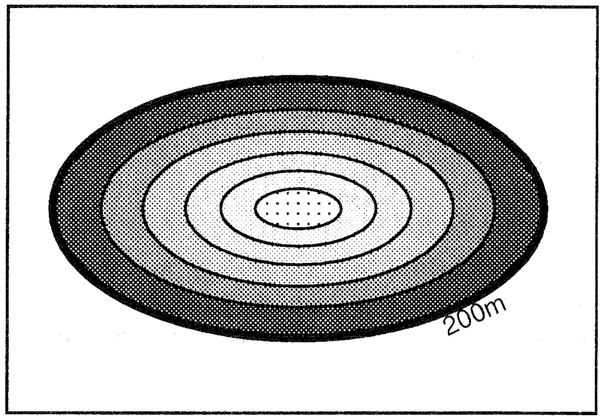

Figure 5 Illustration of buffering results in case o enclosed area with same contour line

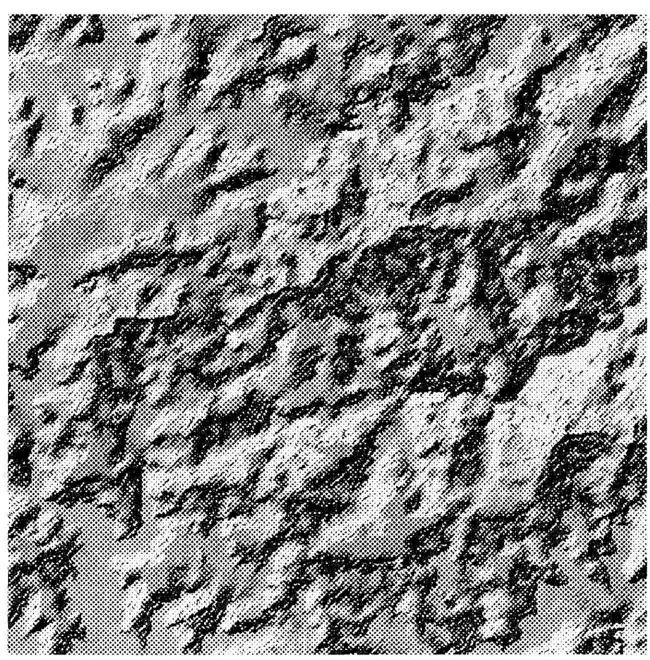

Figure 6 Shaded DEM from Buffering method

this method, the most important thing is definition of extreme value in the enclosed area. An undulation curve was used for extreme value estimation in this study. An undulation curve is expressed a relationship between radius from top of a mountain and the undulation. The undulation means difference between minimum elevation and maximum elevation. It is represented one of the topographical feature. If geological structure is homogeneity, the undulation curve becomes almost same with neighbor mountains. So, when acreage of enclosed area could be calculated, maximum elevation can be estimated.

Finally, a complete DEM can be generated from combination of previous two interpolated DEMs. This method doesn't need searching profile or definition of calculation window size. So, this will be more reliable method. Figure 6 shows shaded image of generated DEM by this developed method using previous contour map. In this figure, there are no noisy area.

4. RESULTS AND EVALUATIONS

Evaluations of buffering method were carried out by comparison with existing methods which are profile method and window method. Items for evaluation are not only elevation but also topographical feature such as slope gradient and slope aspect, stream pattern and slope stability.

Verification data were generated from 5m grid DEM by profile method using 1:25000 topographical maps. The map had enough number of contour line to apply any interpolation methods. The generated 5m grid DEM were resampled to 50m grid size by taking the average in order to make more suitable DEM for verification. 100m, 200m, 300m and 400m interval contour line maps were created from the verification DEM. Those contour line maps were used for DEM generation by using each interpolation method from each contour map.

4.1 Elevation

An index of elevation accuracy is used percentages of correct pixels on the whole pixels. In case of elevation evaluation, correct pixel means difference with verification DEM indicates inside of 20m. Figure 7 shows relationship between contour line interval and correct percentage in each method. In this figure, accuracy has tendency to drop with increasing contour interval. And buffering method is always located the highest accuracy in all contour intervals. Though window method shows almost same accuracy with buffering method in 100m contour interval, the accuracy becomes about 10% less in other contour intervals. Profile method shows the worst results, because radiated noises influence to accuracy.

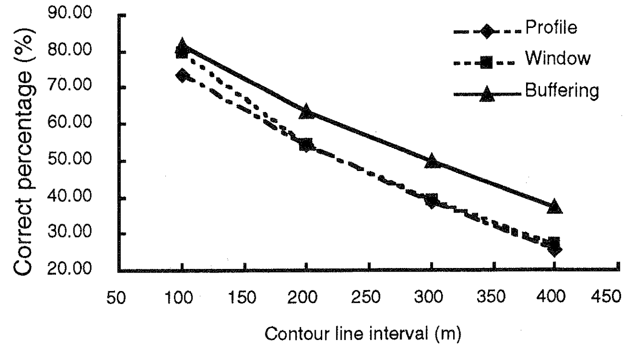

Figure 7 Relationship between contour line interval and correct percentage of elevation

4.2 Slope Gradient

A slope gradient can be expressed from DEM, which is one of the most important items for topographical analysis. In this study, the slope gradient means maximum inclination at one target pixel. An index of slope gradient accuracy is also used percentages of correct pixels. In case of slope gradient accuracy, correct pixel means difference with verification slope gradient data indicates inside of 20 degree. Figure 8 shows relationship between contour line interval and correct percentage in each method. Buffering method is always located the highest accuracy in all contour intervals. Though profile method shows almost same accuracy with buffering method in 100m contour interval, the accuracy becomes 10% less in other contour intervals. The window method shows the worst results, because steep slope along contour line influenced to accuracy.

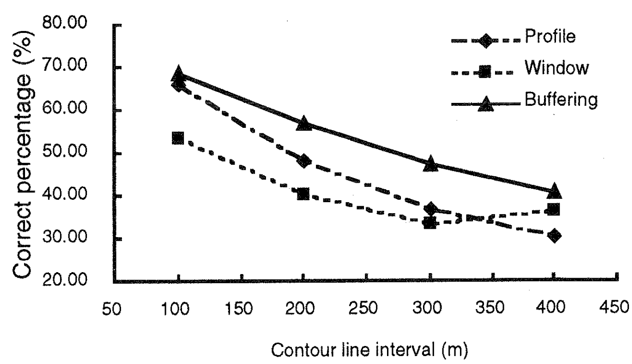

Figure 8 Relationship between contour line interval and correct percentage of slope gradient

4.3 Slope Aspect

A slope aspect can be expressed from DEM, which is one of the most important items for topographical analysis. In this study, the slope aspect shows along the maximum inclination angle at one target pixel. An index of slope aspect accuracy is also used percentages of correct pixels. In case of slope gradient accuracy, correct pixel means difference with verification slope gradient data indicates inside of 45 degree. Figure 9 shows relationship between contour line interval and correct percentage in each method. The correct percentage shows very lower than elevation or slope gradient, which is indicated less than 68%. However, buffering method is almost located the highest accuracy in all contour intervals.

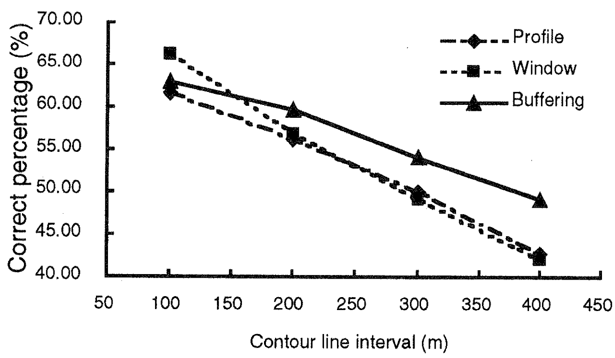

Figure 9 Relationship between contour line interval and correct percentage of slope aspect

4.4 Stream Pattern

A runoff analysis or a stream pattern generation is very popular application of DEM. Usually, such analysis can be carried out by using a grid series tank model. A precipitation is supplied to each DEM grid that is one of the tanks. An inlet content which means effective rainfall for discharge is calculated by following equation.

$$Q_{in} = Ki\, R\, L^2$$

Qin: Inlet Content (m^3)
Ki: Infiltration
R: Precipitation (m)
L: Grid Size (m)

The inlet content must discharge to next grid according to slope aspect and velocity. That is to say flow tracking. The slope aspect can be calculated from DEM, the velocity can be estimated from slope gradient which is also calculated from DEM. And the flow in the grid can be expressed by a continuous equation as follows;

$$Q_{t+\Delta t} = (\Sigma q_{in} - q_{out})\Delta t$$

Q: Remaining Content (m^3)
qin: Inlet (m^3/s)
qout: Outlet (m^3/s)
Δt: Time (s)

By using previous equations, stream pattern can be drawn. In this study, a parameter of infiltration was given 1.0, because purpose is just DEM evaluation.

An index of stream pattern accuracy is also used percentages of correct pixels. In this case, correct pixel means difference with verification discharge value indicates inside of 20 m^3/s. Figure 10 shows relationship between contour line interval and correct percentage in each method. Buffering method is almost located high accuracy. However, in 400m contour interval, buffering method indicated the worst accuracy. The discharge accuracy is influenced by slope aspect. Though the slope aspect of buffering method kept the highest accuracy, stream pattern accuracy didn't keep it. This reason might come from difference of aspect distribution.

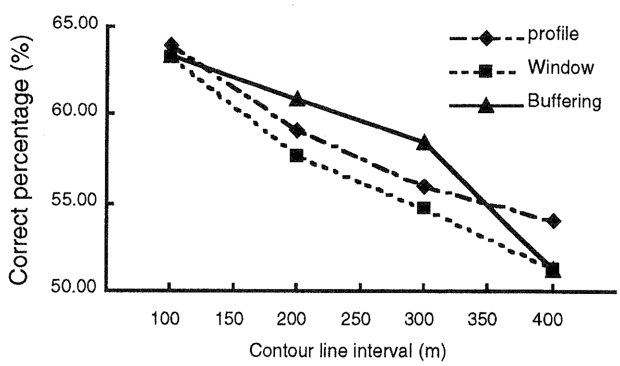

Figure 10 Relationship between contour line interval and correct percentage of stream pattern

4.5 Slope Stability

A slope stability analysis is also popular application of DEM. Sometime we generate land slide risk map or slope failure risk map from DEM. The slope stability which means safety factor was

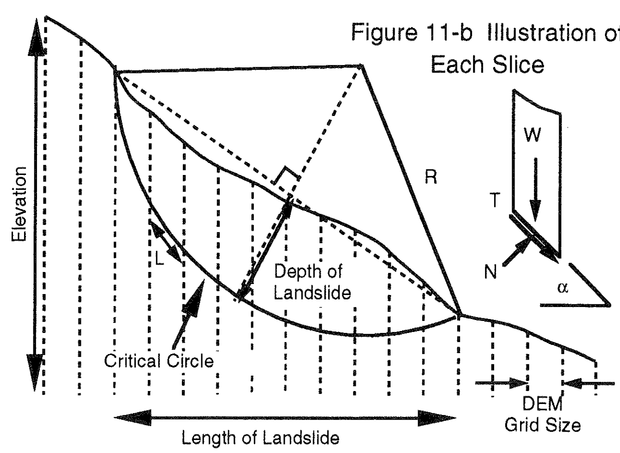

Figure 11-a Illustration of Fellenius Method

calculated by a ratio between driving moment and resistance moment on the profile. When the safety factor is calculated on every pixel, such risk map can be generated. Fellenius method as slope stability analysis was selected in this study. In this method, landslide type is assumed rotational slip (Figure 11). A landslide soil is divided into some slices in order to calculate moment along the critical circle. The driving moment(T) and resistance moment(N) on each slice are calculated by the following equation.

$$T = R \cdot W \cdot \sin\alpha$$

$$N = R(C \cdot L + \tan\phi \cdot W \cdot \cos\alpha)$$

R	Radius of Critical Surface (m)
C	Cohesion (t/m^2)
ϕ	Angle of Shearing Resistance (degree)
W	Weight of Each Slice (t/m) ($W = \gamma_t A$)
γ_t	Wet Unit Weight of Soil (t/m^3)
A	Area of Slice (m^2)
α	Angle between Horizontal Axis and the Base of Slice (degree)
L	Length of the Base of Slice (m)

Therefore safety factor(Fs) is calculated by the following equation.

$$Fs = \frac{\Sigma N}{\Sigma T}$$

Originally, parameters of soil mechanics (C, ϕ, γ_t) and radius of critical surface (R) should be determined by experimental data and field survey data on each pixel. In this study, those parameters were given by constant value as follows:

$R = 200m$, $C = 2.0t/m^2$, $\phi = 10°$, $\gamma_t = 1.9t/m^3$

When profile at target pixel was drawn along the steepest direction, Other parameters can be estimated by DEM. If this safety factor calculation applied every pixel, slope stability risk can be mapped.

An index of safety factor accuracy is also used percentages of correct pixels. In this case, correct pixel means difference with verification safety factor value indicates inside of 0.2. Figure 12 shows relationship between contour line interval and correct percentage in each method. Buffering method is always located the highest accuracy. The safety factor accuracy requires slope gradient and slope aspect. Buffering method made very good result for slope stability analysis.

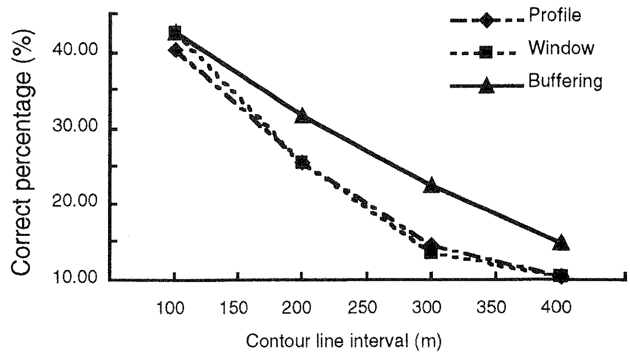

Figure 12 Relationship between contour line interval and correct percentage of slope stability

6. CONCLUSIONS

When existing interpolation method used for small scale contour map, some problems were occurred. For example, profile method has much error in elevation value. Window method has much error in slope gradient.

In this study, buffering method was developed for continental DEM generation from a small scale map. The developed method was compared with existing methods on elevation, slope gradient, slope aspect, stream pattern and slope stability. In all items, the buffering method showed the best results.

A contour line interval influenced accuracy of DEM. When contour line interval becomes over 300m, a correct percentage becomes less than 50%. A percentage of pixels which are consisted contour line is about 10% in case of 300m contour interval. Moreover, in case of 100m contour interval, the percentage becomes 30%. Therefore, at least 20% contour line information on whole map are required for reliable DEM generation.

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