DATA STRUCTURE RESEARCH OF 3D CITY ROAD NETWORK

Min **SUN**[*] Jun **CHEN**[**]
*. Institute of Surveying and Mapping
Central South University of Technology, Changsha, 410083, China
**. National Geomatics Center of China
Beishengcun, No.1 Zizhuyuan, Beijing, 100044, China, sm6811@263.net

KEY WORDS: Road network, 3DGIS, Cloverleaf Junction, Data model.

ABSTRACT

Data management of city road network is still resting on two dimensional data model, however, with the development of city traffic, many kinds of interchanges are constructed, this made the city road network becoming very complex, and form a complicated three dimensional network. Therefore, it's difficult to express the 3D spatial characters of the city road network using two dimensional data model that widely used in 2DGIS. On the other hand, with the development of many application systems such as: Intelligent Transportation System, Road organizes and design system and many other pipeline systems; demands for three dimensional road network data are becoming urgent. For those reason, we firstly point out the limitation of the two dimensional data model when it used to express the three dimensional road network, then analyze spatial characters of the three dimensional road network, finally we put forward a three dimensional road data structure, which can overcome the limitation of the present two dimensional data structure.

1 INTRODUCTION

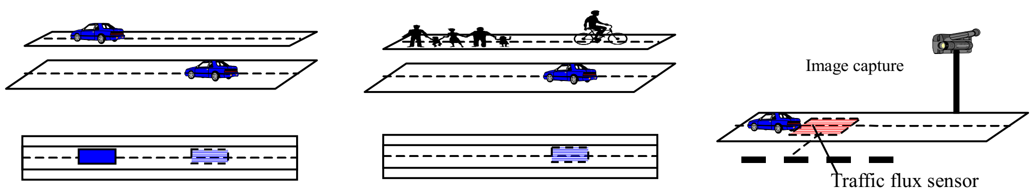
City road has many very important functions, such as: connect city parts, provide many traffic services, construct a framework for city structure, lay many kinds public establishments, partition street blocks and organize buildings along street, etc. (Sun J., 1997). With the rapid development of city traffic, road plays an more and more important role, digitized road data now has an very extensive application in traffic transportation, traffic guidance, fire fighting, road line design and city layout. The European Digital Road Map is the most advance research achievement about road network, GDF used as a standard of data exchange (Walter V. 1994). In china, many information systems based on road network are established (Cao G. 1995; Yang Z. 1998). But data management of all these systems are based on 2-Dimension data model, and 2D data model can only fulfill road information disposal in small scales, especially its unsuitable to express complex city road information, following are some reason that we need 3D dimensional data model:

- 2D data model can't fulfill the representation for city road network that becomes more and more complex:
  1) The proportion of interchanges in road network is increasing, this made city road becomes more and more complex;
  2) It's difficult for 2DGIS data model to describe the 3D spatial characters of the modern road network, e.g., road middle line itself is a 3D spatial curve, at the same time, there exist complex relationships between road segments;
  3) Complex interchanges in whole city are can't be disposed as a simple node: many interchanges occupy more

than ten-thousands square meter areas, and usually composed by several or even more bridges, have at least two or more layers;

- ❑ Many kinds traffic manage systems, traffic guidance systems are need true 3D road data:

1) As the complexity of city road, one point on plane can't locate vehicle position (see fig.1.a);
2) The division is necessary for various kinds of road that projection is overlapped (see fig. 1.b);
3) Layout design and maintenance for various traffic establishment (e.g.: sign collect equipment) (see fig.1.c);



(a) (b) (c)

Fig.1 Complexity of city road network

- ❑ Layout of many pipeline systems that lay along the city road need true 3D road data, those pipelines mainly include: communication line, electronic line, water pipeline, gas pipeline and cloacae, etc.
- ❑ 3D road network is the framework of 3D City Model, road network decide layout of city and also some relationships of city blocks (see fig. 2);
- ❑ 3D data of city road can be used in many areas (see fig.3);

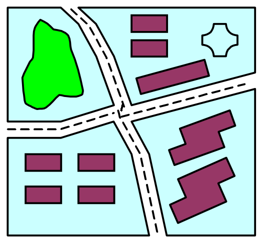


Fig.2

Therefore, establish a 3D road network data model, and use it to express complex 3D spatial character of city road, describe complex relationships between road segments has great significance. At first, we analysis the limitation of 2D Data model in express 3D city road network.

2 THE LIMITATION OF 2DGIS DATA MODEL USED TO EXPRESS 3D ROAD NETWORK

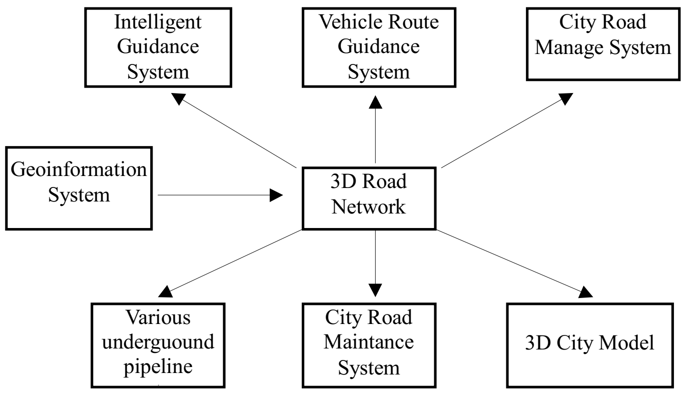


Fig.3. Relations between city road network and various application systems

The majority of GIS spatial data is digitized from maps or spatial images, and many popular GIS software (such as: Arc/Info, MapInfo) are all established on 2D data model. If the spatial data of road network managed by 2DGIS software, the data management of road network is certainly base on 2D data model. Road network data is mainly used in traffic area, and there are many kinds model was established for road network data, such as: weight model, experiential model, etc. Because those models are all established on small-scale map, road network is usually considered as a composing of nodes and edges, nodes represent road crossing and station, edges represent segments (Song W. 1996). Walter V.(1994) put forward a 2D road concept data model based on GDF, at same time, he put forward a 2D data organize scheme. In this scheme 2D points and lines are used to express road network, and layers are used to organize different types of road spatial objects, and Virtual node is used to express virtual intersection of two line segments. Because this concept model also based on 2D data model, same limitation can't avoid expressing the 3D spatial characters of road network.

Virtual node is typically introduced into Arc/Info, but it has following limitation:

- Must disconnect two virtual intersect lines, this means two lines and two nodes must be added, therefore, not only increase amount of data, but also the complexity of data management;
- Spatial data of Virtual node can't express virtual intersection of two spatial lines, therefore, attribute value is used in topological relationship establishment, this increase complexity of spatial data operation;
- When plane projections of two virtual intersection is overlapped, e.g.: one road segment pass through the middle of two up down parallel road segments, virtual node would be puzzled;

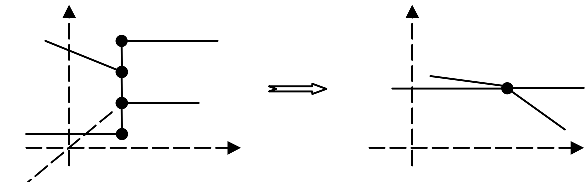


Fig.4.a. Case of multi node projection overlapped

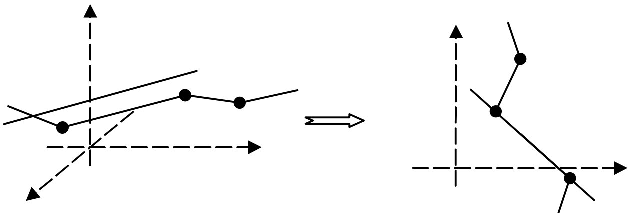


Fig.4.b. Case of two segment projection overlapped

Besides the limitation of virtual node, 2D data model still has other limitation when it's used to describe 3D-road network:

- Plane points and lines are difficult to express third spatial information, and easily effects spatial data integrality;
- It’s difficult to fulfill topology analysis and operation for third dimensional data;
- It’s difficult to realize 3D visualization;

Actually, for special application, 2D data model has different degree limitation. Fig.4 shows two cases that 2D spatial data model can’t disposal.

On the other hand, in the research of common 3DGIS data model, many scholars put forward many valuable data model or data structure (such as: Molenaar 1992, Li R. 1992, Morakot P. 1994, Peter O. 1995, Chen X. 1995, Tempfli K. 1996, Karine et al.1996, Gong J., Xia. Z. 1997, Chen J., Guo W. 1998). But at the present time, there were no any 3DGIS software successfully developed from those common 3DGIS data model, while for road network, there were also no any special solutions has been put forward. Despite of the fact that Intelligent Transportation System, Vehicle Information Guidance System and Vehicle Route Guidance System are all international research hotspot, all those research are mainly combination of GPS and GIS, and their spatial data management is rely on GIS.

So, for small-scale road network data, 2D data model can basically satisfies needs, because in this case, road intersection can be completely represented with node. But during the large-scale road data disposal, interchanges can't be neglected; moreover, interchanges data occupies a great proportion in large city road network, and it’s the most difficult part to deal with. Therefore, research of 3D data structure for road network is very important.

3 3D ROAD NETWORK SPATIAL CHARACTER ANALYSIS

Because city scope enlarges and traffic pressure is increasing, road network is forced to develop from ground to aerial. Ground crossings become interchanges, including cloverleaf junction, overbridge and subway, among those interchanges, cloverleaf junction is the most complex, overbridge and subway are mainly supply for foot passengers, it's relatively simple. Here we mainly discuss cloverleaf junction (the following text we use word 'interchange' instead of 'cloverleaf junction'). How to efficiently express the 3D road network, it should firstly solve the expression of interchanges. In conventional road data model, because interchanges are considered as nodes, so conventional road data model is a plane 2D network. In the plane road network, road is divided into road segment and road crossing, respectively expressed by line and node. In the situation without consideration of interchanges, conventional road data model can commendably describe city road network, there are two reasons as following:

- Without consideration of interchanges, city road is mainly ground road, road segment and road crossing is the basic elements compose of plane road;
- For many application such as traffic flux analysis, traffic distribution and traffic flux forecast, this data model is good enough to solve questions;

But because of the emergence of interchanges, this conventional 2D road network data model faces a very serious challenge. Fig.5 shows a simple road network, edge is road segment, and node is road crossing. If star signed nodes denote interchanges, then this road network is no longer a 2D network, but is a 3D network. If consider interchange as a node, then question is solved. But the emergence of interchange made road network very complex, and interchange itself plays a very important role. For example, in Beijing, 6 transmeridional trunks, 3 south-north trunks, 4 ring roads and 9 radiate roads compose the framework of the present Beijing road network. There are about 63 interchanges in this whole road network (Xia Q., 1992). Each interchange not only occupies very large area, but also has a very complex connectivity. E.g. Caihuying interchange that is not the most complex interchange, lies on the northwest of second ring road, totally has three layers, 112 flyovers and 2500 meters long, composed by 19 bridges. It's overriding rivers, highways and railway, connect Lize interchange and Youanmen interchange from east to west, connect Yuquanying ring island and Baizhifang interchange from north to south, and occupy 500,000 square meters area, therefore, such an interchange can't be disposed as one node. From the classified definition and it's composing, we can conclude following spatial character for interchange (fig.6 is several interchange types and basic composing, fig.7 is interchange structure composing):

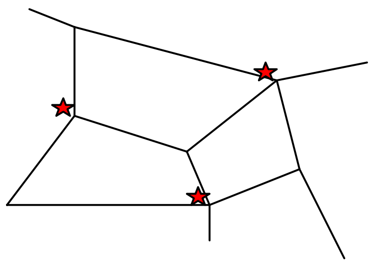


Fig.5. Plane 2D road network

- Has 3D spatial layers, at least two road layers, usually connect from up to down with circle way;
- It's main traffic way composed by circle way and main way;
- It's driveway has relatively fixed direction, and driveway can express it's connectivity; It's spatial geometry figure is regular, usually is combination of curve and straight line;

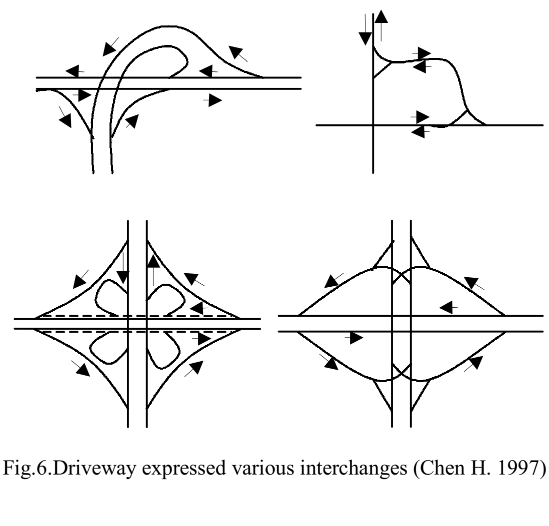


Fig.6.Driveway expressed various interchanges (Chen H. 1997)

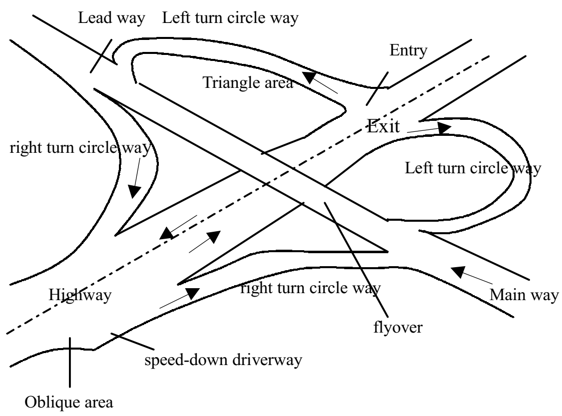


Fig.7. Composing of cloverleaf junction (Hongren Chen, 1997)

We can draw a conclusion that there exist virtual intersection segments on interchange, those road segments usually connect each other. In order to analysis spatial character of interchange, we construct ER diagram for interchange, see fig.8:

From this diagram, we can find that interchange can be divide into a set of road segments and road crossings, therefore 3D road network can be expressed with uniform entity: road segment and road crossing, from this point, a 3D data model can be established based on this two entities.

4 3D CITY ROAD NETWORK DATA STRUCTURE

Based on above analysis, road network has two entities: road segment and road crossing, then concept data model can be established as in fig.9.

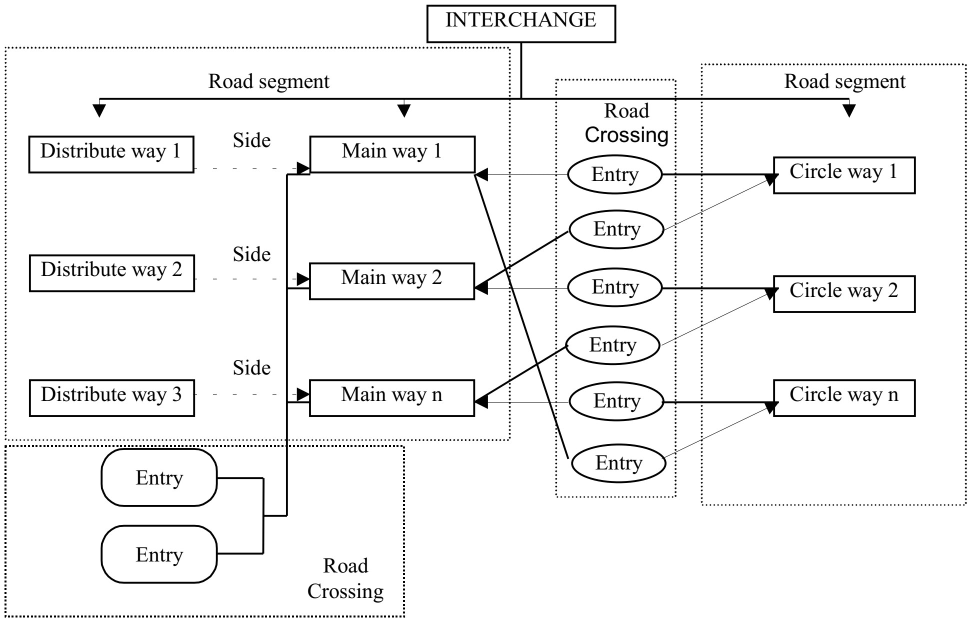


Fig.8. Interchange ER diagram

One segment uses two crossing as its end, but one crossing corresponding to several segments. Road segment usually divided by road crossing, namely, the part of road between two road crossings is road segment, because interchange usually emerges in crossing position, it's usually considered as node in traditional data model, in order to uniform the concepts in data model, we represent interchange with complex crossing, and this disposal is same as the idea of map generalization. But interchange itself is composing of a set of road segment and road crossing. Therefore interchange is disposed as a complex node. In data model, if we use edge express road segment, node express road crossing, then we can construct data structure as in fig.10. Define classes of road segment and road crossing as in follow:

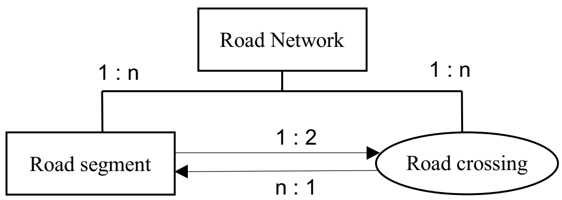


Fig.9. Road network ER model

Road segment: as above illustrate, the part of road between two adjacent road crossing is road segment. Because road middle line can basically represent spatial character of road segment, and road sidelines are very important in road segment position describing and road visualization, so road spatial data is composing of middle line and sidelines.

Common crossing: the place of multi road segments intersection is common crossing, use a certain spatial area express it's position, and use 3D point express it in road topology network.

Complex crossing: inherited from common crossing, and used to describe interchange.

Road segment:

{

Spatial data: road middle lines, sidelines;

Start and end crossing: A, B;

Attribute data: degree, direction and various equipments;

}

Common crossing:

{

Spatial data: spatial position, spatial coordinate (x, y, z);

Adjacent road segment: A, B;

Attribute data: various equipments;

}

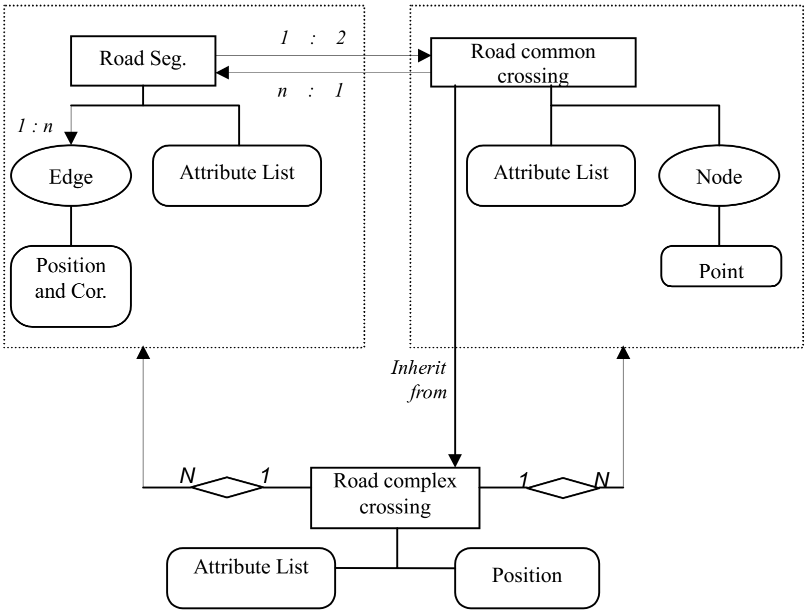


Fig.10. 3D data structure of city road network

Complex crossing:

{

Spatial data: a set of road segment, crossing and their spatial relationships, plane position (polygon or point);

Adjacent road segment A, B, C…;

Attribute data: degree, direction and various equipments;

(for various type interchange, spatial data and attribute data is defined by group)

}

For above data structure we have following discussion:

1. About complex crossing: complex is a super class, itself compose of segment and crossing, but because its inherited from common crossing, so complex crossing can be simplified to be common crossing. When complex crossing simplified into common crossing, then road network simplified from 3D to 2D, and can be disposed in conventional way.

2. Establish topological relationship: road connectivity has a following mathematic definition:
   Topological space X has road connectivity, if $\forall x, y \in X$, in X exist road which start point is x and end point is y.
   Obviously, the 3D data structure we established is at least partly has road connectivity; this can be illustrated as following:
   Road segment can be regarded as a topological space road, two road crossing connect to this road segment can be regarded as start point and end point, namely terminal, each terminal at least is a start point or end point of one road, then:

- □ For any point in any road, there must exist one node connect with it;
- □ Exist one adjacent area, for two arbitrary node, there must exist at least one path formed by at least one road connect each other;
- □ Therefore, exist one adjacent area, for two arbitrary point, there must exist path connect each other;

3. In actual traffic, drive direction is decided by driveway, while driveway usually has a proportion 1:N with road

middle line, that's there are several driveway in one road segment, thus, in data model one road segment should has many spatial lines to describe it. However, driveway and road middle line have a great similarity, the data of driveway can calculate from the data of road middle lines, from this reason, we can simplify spatial geometry data management;

4. Because spatial data of road segment and road crossing are no longer 2D lines and points, and spatial third information is included in spatial data model, so the situation of virtual intersection can be fully and directly expressed.

5 CONCLUSION

With the development of modern City, road network developed from plane to interchange, road network actually is a complex 3D network, so it's difficult to describe this 3D road network using 2DGIS. Especially in large scale, how to efficiently express, organize and manage road data is very difficult, on the other hand, the present 3DGIS research seldom relate to 3D road network expression, however, the expression and management of road network data is very important. For those reason, we analysis the present 2DGIS limitation in express 3D road network, and put forward to divide road network into segment and crossing, and road crossing is divided into common crossing and complex crossing, use complex crossing express interchange, while one complex crossing is composed by road segment and common crossing. From this way, establish a data structure for 3D road network, in this data structure, road segment is expressed by edge, road crossing is expressed by 3D point. Our further work is research on spatial topological relationship and spatial operation in 3D road network.

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Relationship between Spatial Resolution and Terrain Feature in DEM Accuracy

Masataka TAKAGI
Department of Infrastructure Systems Engineering
Kochi University of Technology
http://www.infra.kochi-tech.ac.jp/takagi/
takagi@infra.kochi-tech.ac.jp

Working Group IV/4

KEY WORDS: DEM, Accuracy, Spatial Resolution, Terrain, Topography

ABSTRACT

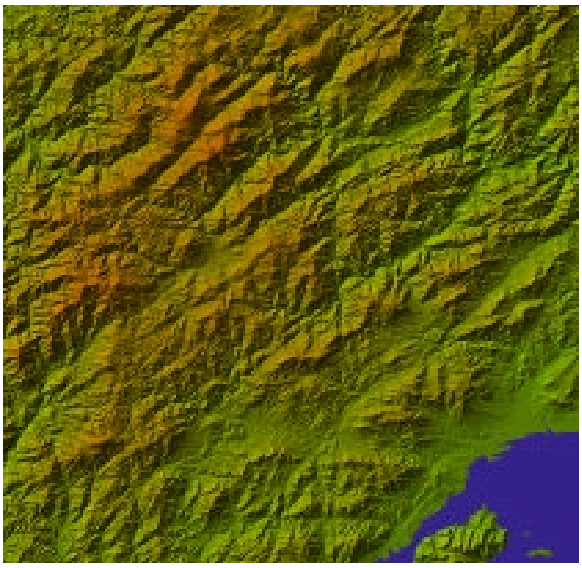
Digital Elevation Model (DEM) is indispensable for many analyses such as topographic feature extraction, runoff analysis, slope stability analysis and so on. Such analyses require a high accurate DEM. The accuracy of DEM is usually represented by spatial resolution and height accuracy. In this paper, the accuracy of DEM will be evaluated according to spatial resolution and terrain feature.
DEMs of various spatial resolution and various terrain were prepared for evaluation. Using these DEMs, slope inclination extraction, slope aspect extraction, drainage pattern generation and slope stability analysis were carried out. Results of each analysis were compared according to spatial resolution. The results showed spatial resolution seriously influenced on accuracy of inclination. The tendency especially marked in metamorphic area because of steep terrain. Slope stability analysis was also influenced because inclination is using in this analysis. The tendency especially marked in granite area because of complicated terrain. Drainage pattern generation was influenced slightly. Catchment area influences drainage pattern generation. Catchment area which is generated from spatial distribution of slope aspect might be kept regardless with spatial resolution.

1 INTRODUCTION

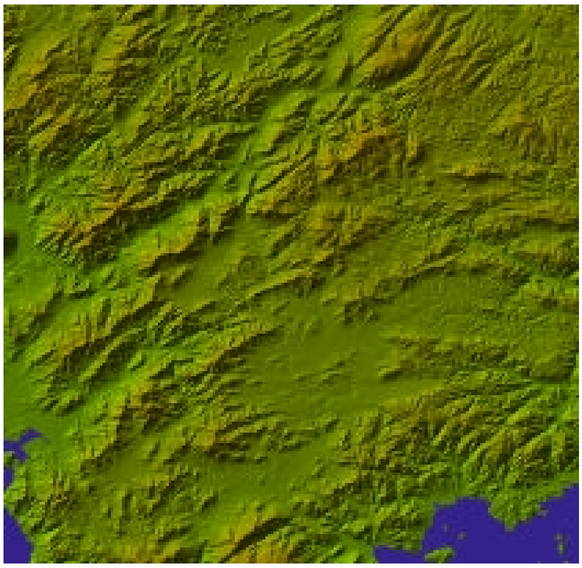
There are many kinds of DEM (Digital Elevation Model) generation methods such as a stereo-matching from satellite image, an interferometry from SAR data and an interpolation of topographic maps. On the other hand, we can use some accomplished DEMs. For example, NGDC NOAA offers global land one-km base elevation (GLOBE). And, USGS offers Digital Chart of the World that has elevation information also. Moreover, NASA has a project which is named SRTM (Shuttle Radar Topography Mission). SRTM will offer 20m spatial resolution dataset covered about 80% of all the land on the earth. Each DEM has various grid size and various elevation accuracy.
DEM is indispensable for many analyses such as topographic feature extraction, runoff analysis, slope stability analysis, landscape analysis and so on. We must consider which accuracy is appropriate for any analyses. Therefore, study of DEM accuracy becomes very important.
In this study, an accuracy of DEM according to spatial resolution will be evaluated. A relationship between spatial resolution and terrain feature in DEM accuracy will be concluded. DEM accuracy will be influenced by terrain.We prepared a various grid size of DEMs in two representative geology where is granite area and metamorphic rock area. In each area, terrain feature is much different. The DEMs will be used for topographical analysis, slope stability analysis and runoff analysis. After that, results from resampled rough DEM will be compared with result from original DEM.

2 MATERIALS

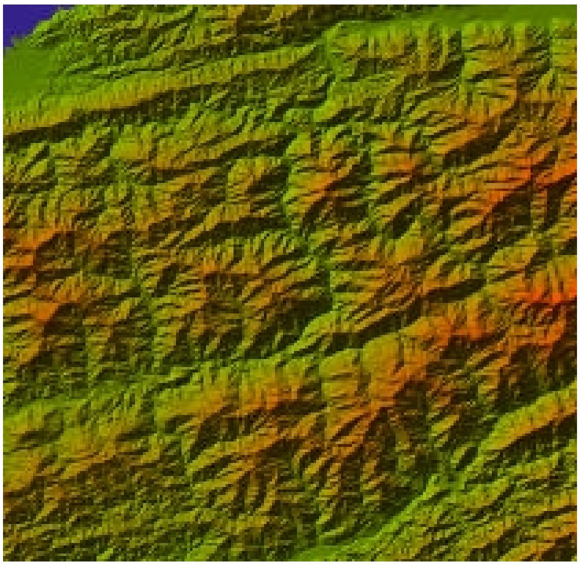
An original DEM was grid model which is 50m grid published from Geographical Survey Institute, Japan. The DEM is prepared whole area of Japan. As study area, granite area and metamorphic rock area is selected. Each area is much different in terrain feature. Figure 1 shows a shaded image of the original DEM. Granite area shows gentle slope and there are small and complicated undulations. Metamorphic rock area shows steep slope and there are many tectonic line and chains of mountains.
For evaluation of spatial resolution, a various grid size DEM was derived from the original DEM. In this study, 100m, 150m, 200m and 250m grid size DEMs were generated by nearest neighbor resampling.



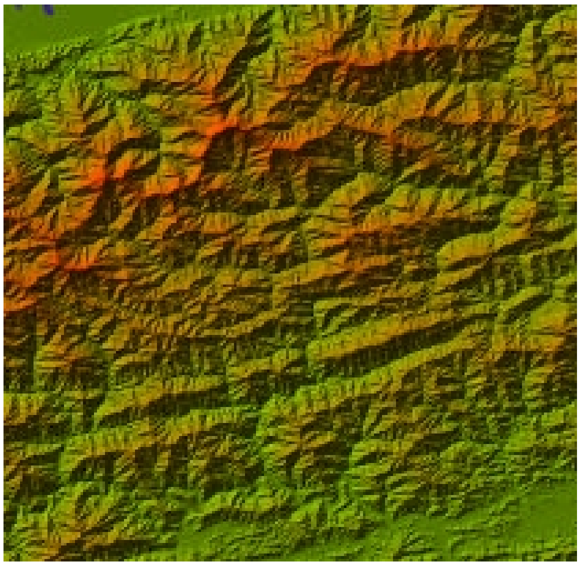
a-1: Granite 1 area



a-2: Granite 2 area



b-1: Metamorphic 1 area



b-2: Metamorphic 2 area

Figre 1 Shaded Image of Original DEM

3 EVALUATIONS OF DEM ACCURACY

3.1 Slope Aspect Accuracy and Terrain Feature

A slope aspect can be expressed from DEM, which is one of the most important items for topographical analysis. In this study, slope aspect was defined by a direction along the maximum slope inclination. There are eight pixels around a target pixel on DEM. The slope inclination can be calculated along the eight directions.

Figure 2 shows a relationship between grid size and ratio of correct pixels. The correct pixel means difference indicates inside of 45 degree. In this figure, the ratio of correct pixels has tendency to drop with grid size increase. The result showed very similar with same geology. In granite area, accuracy indicates lower.

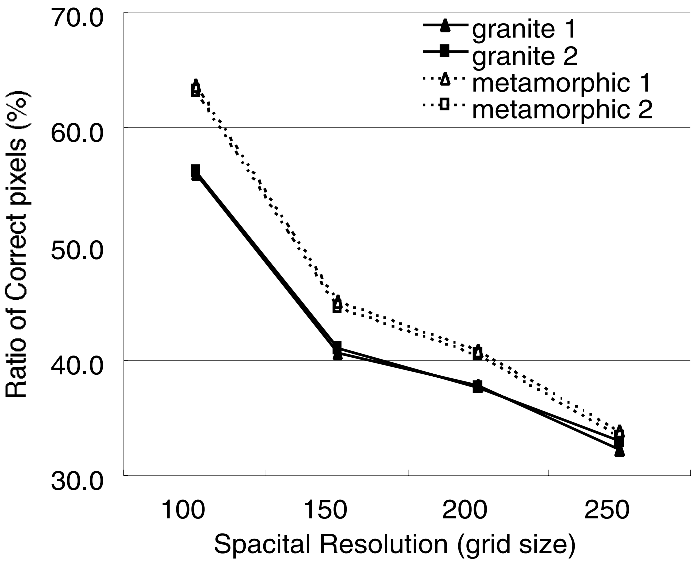


Figure 2. Accuracy of Slope Aspect

3.2 Slope Inclination Accuracy and Terrain Feature

A slope inclination can be expressed from DEM, which is also one of the most important items for topographical analysis. In this study, the inclination was defined by maximum slope inclination at a target pixel.
Figure 3 shows a relationship between grid size and ratio of correct pixels. In case of slope inclination, correct pixel means difference indicates inside of 20 degree. The correct pixel in metamorphic area indicates almost 40 % in even 100m grid size. It will be serious problem. However, the correct pixel in granite 2 area keeps over 60%. Granite 1 area shows different result from granite 2 area. It is similar to metamorphic area. Metamorphic area and granite 1 area has very high mountains. The situation might be influenced inclination accuracy.

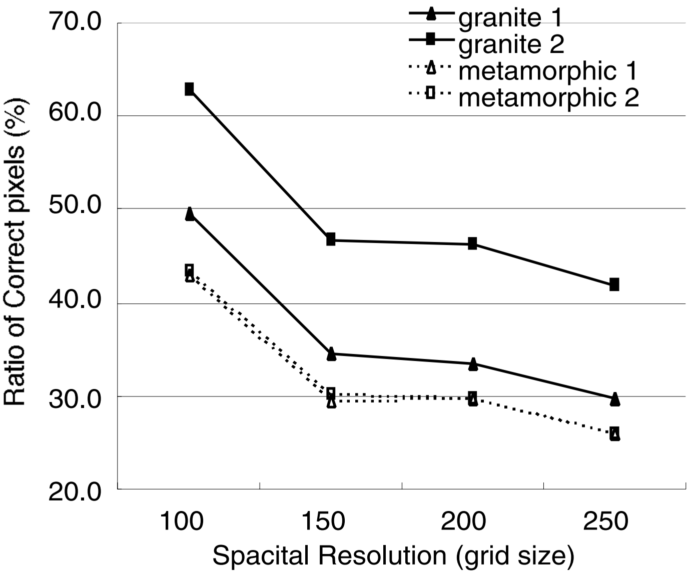


Figure 3. Accuracy of Slope Inclination

3.3 Drainage Pattern Accuracy and Terrain Feature

A runoff analysis or a drainage pattern generation is very popular application of DEM. Usually, such analysis can be carried out by using a series grid tank model. A precipitation is supplied to each grid of DEM which means one of the tanks. An inlet content which is 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 inclination which is also calculated from DEM. And the flow in the grid can be expressed by a continuous equation as follows;

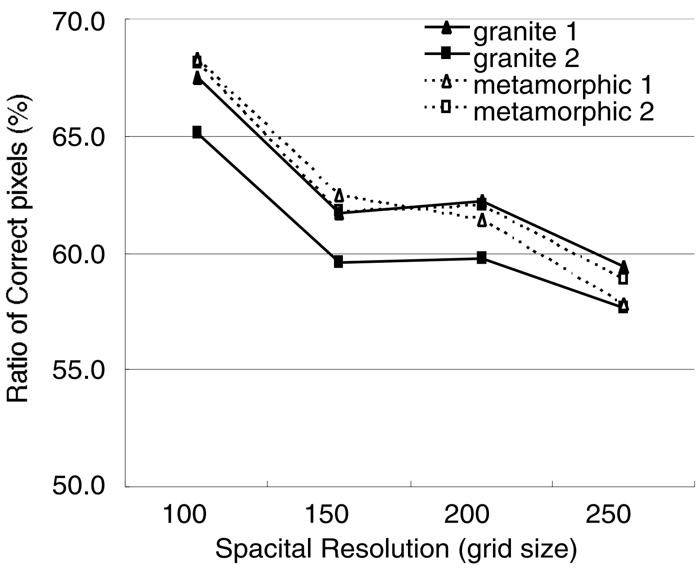


Figure 4. Accuracy of Drainage Pattern

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

Q: Remaining Content (m^3)
q_{in}: Inlet (m^3/s)
q_{out}: Outlet (m^3/s)
Δt: Time (s)

By using previous equations, drainage pattern can be drawn. In this study, a parameter of infiltration was given 1.0, because purpose of this analysis is just evaluation of DEM. In this analysis, spatial distribution of slope aspect and slope inclination will be concluded.
Figure 4 shows a relationship between grid size and ratio of correct pixels. In case of runoff analysis, correct pixel means difference indicates inside of 20 m^3/s. The correct pixel indicates over 55% in even 250m gird. It was unexpected. Granite 2 area shows lowest accuracy. It is opposite results from inclination accuracy. It might be influenced from complicated undulations. The complicated undulations makes low accuracy in drainage pattern according to low spatial resolution.

3.4 Slope Stability Accuracy and Terrain Feature

A slope stability analysis is popular application of DEM. Sometime we generate land slide risk map or slope failure risk map from DEM. The slope stability defined by safety factor which can be calculated by a ratio of driving moment to resistance moment along a profile of terrain. When the safety factor is calculated on every pixel, slope stability map can be generated. Fellenius method as slope stability analysis was selected in this study. In Fellenius method, landslide type is assumed rotational slip (Figure 5-a). A landslide soil is divided into some slices in order to calculate moment along the critical circle (Figure 5-b). 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)

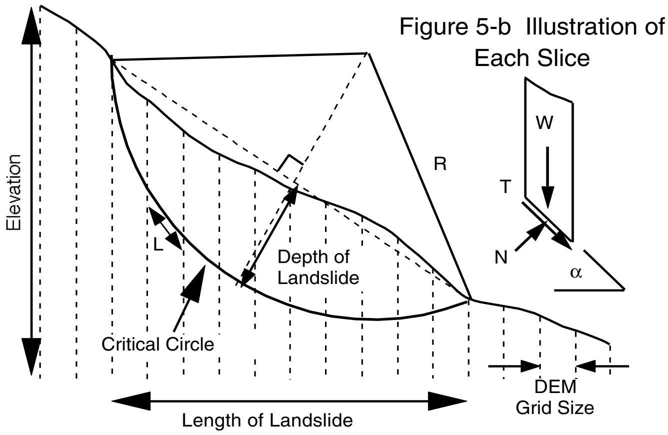


Figure 5-a Illustration of Fellenius Method

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 or field survey data on every pixel. In this study, those parameters were given constant value as follows:

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

When profile at target pixel was drawn along the steepest direction, Other parameters (W, L) can be calculated by DEM. If the safety factor calculation applied every pixel, slope stability map can be mapped. In this analysis, combination of slope aspect and slope inclination will be concluded.

Figure 6 shows a relationship between grid size and ratio of correct pixels. In case of slope stability, correct pixel means difference indicates inside of 0.2 (Fs). The correct pixel in metamorphic area indicates higher accuracy. The tendency of accuracy is similar to drainage pattern. Moreover, low spatial resolution makes extremely low accuracy in slope stability analysis. Granite area has complicated undulations. The situation might be influenced the analysis accuracy.

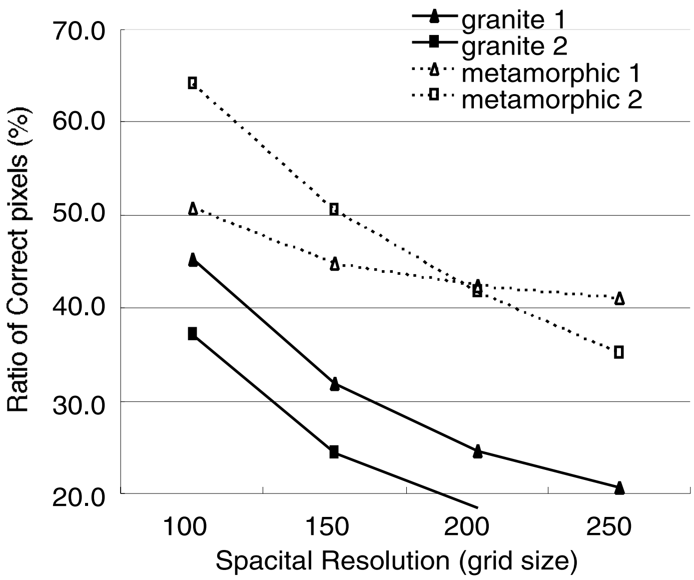


Figure 6. Accuracy of Slope Stabiilty

4 CONCLUSIONS

In this study, an accuracy of DEM according to spatial resolution was considered. Spatial resolution influenced sensitively to slope inclination rather than slope aspect. A terrain surface generally undulate in even one pixel, so that such detailed terrain is neglected by low spatial resolution. The tendency especially marked in metamorphic area because of steep topography.

On the other hand, spatial resolution is slightly influenced to drainage pattern generation. The drainage pattern can be generated by flow tracking which uses spatial distribution of slope aspect. Originally, the drainage pattern is influenced by catchment area. So, catchment area might be kept regardless with spatial resolution.
In slope stability analysis, accuracy is influenced by combination of inclination and aspect. The result showed low spatial resolution made lower accuracy. The tendency especially marked in granite area because of complicated topography. Complicated undulations may make lower accuracy.
Almost terrain analyses use combination of slope aspect and inclination. So, we must take care to use low spatial resolution DEM. In this study, the highest spatial resolution was 50m grid DEM. However, we can use less than 10m grid because very high resolution satellite can be used now. In future, such very high resolution DEM must be evaluated. A spatial resolution was very important for any analysis.

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