Comparative Study On Generation of Optimal Digital Elevation Model

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Abstract

National Geographic Information Institute (NGII) in Korea, through National Geographic Information System (NGIS) Program, has prepared to generate and disseminate digital elevation data for Korea. This is a pilot research to propose a policy for production, maintenance, and supply of Korea Digital Elevation Data (KDED).

Customer demands for accuracy and resolution of DEM was surveyed through questionnaire. In order to investigate the quality, the technical efficiency and the production cost, a tentative DEM in a small test site was generated based on digital topographic maps (original paper map scale 1:5,000), analytical plotter, and LIDAR. Accuracy standard for KDED was derived based on source data and generation methods.

As results of this research, uniformly spaced grid model was recommended for KDED. Its preferable grid space is 5m in urban and its vicinity, and 10m in field and mountainous area. LIDAR has been valuated as a proper KDED generation method fulfilling customers demand for the accuracy.

1. Introduction

DEM is a generic term for digital topographic and/ or bathymetric data, in all its various form. It is called a "model" because computers can use such data to model and automatically analyze the Earth's topography in 3-dimensions, minimizing the need for labor-intensive human interpretation. Unless specifically referenced as a Digital Surface Model (DSM), the generic DEM normally implies elevation of terrain (bare earth z-values) void of vegetation and man made features. This bare-earth DEM is generally synonymous with a Digital Terrain Model (DTM). As used by U.S. Geological Survey (USGS), a DEM is the digital cartographic representation of the elevation of the terrain at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum (Maune, 2001).

Before the establishment of "the Base Plans for Construction of National Geographic Information System (NGIS)" in Korea, the related Departments of Korean Government, research institute and private corporation had generated DEM on local area for their projects using various data existed. Each DEM produced for special projects has some problems related to the quality, the reality, the coordinates system, the duplication and so on. Therefore, there are needs to establish the standard model and production methods of DEM for Korea. It will assure us the high quality and the enhanced usability of DEM. It will prevent us from producing DEM on an area where DEM was produced already. Moreover, many user want high quality DEMs produced by new technology in these years. So it is also requisite to study the performance and economic efficiency of the new technology for DEMs production.

This study includes investigations of the fundamentals of DEM. Customer demands for the accuracy and the resolution of DEMs were surveyed through questionnaire. A pilot DEM in a small site was produced based on digital topographic maps (original paper map’s scale 1:5,000), analytical plotter, and LIDAR. Accuracy standards for Korean DEMs were derived based on source data and production methods. Based on the analysis of this pilot DEM production, a scheme for the DEM production in Korea is proposed.

2. Questionnaire for DEMs

In order to review the demands of user and producer of DEMs, a questionnaire was sent to 65 organizations including the related Departments of Government, research institutes, private corporations, and universities. The questionnaire contains some questions about the use and the production experience of DEMs, any plans for use of DEMs in the future, and preferable standards of DEMs for Korea.

2.1 The experience of Production and use of DEMs

1) Have you ever produced DEM?

Among the people answered to the questionnaire, the ratio of people who have ever produced DEM was 64.2 %.

2) When did you produce DEM?

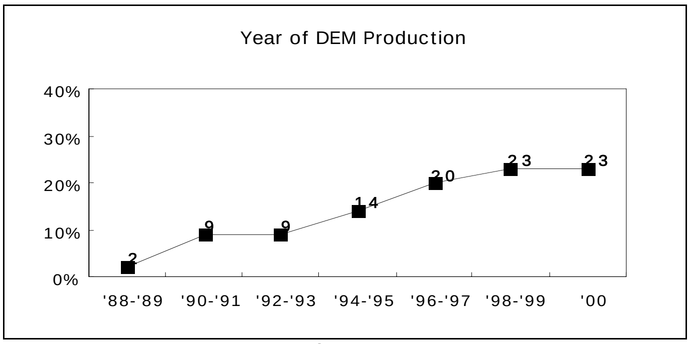


Fig. 1 Year of DEM Production

3) What was the purpose for DEM production?

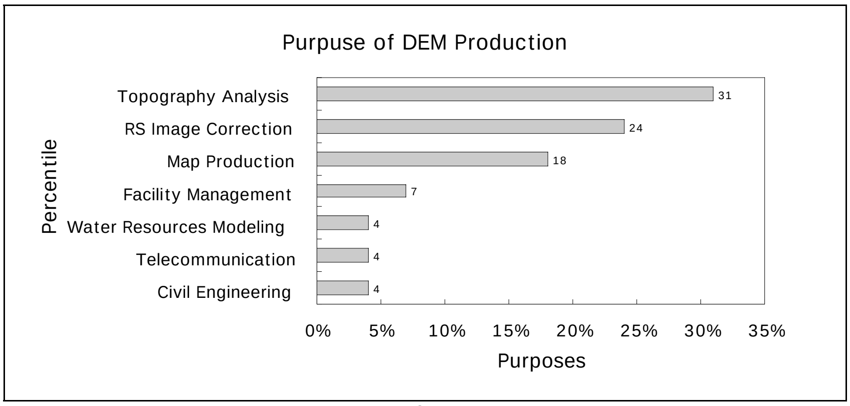


Fig. 2 Purpose of DEM Production

4) What method did you use for DEM production?

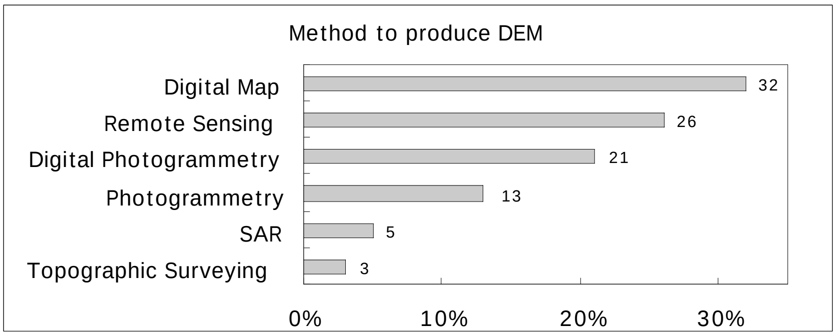


Fig. 3 Method of DEM Production

5) What is the preferable grid space for the purpose of DEM use?

Table. 1 Preferable Grid Spaces for the Purpose of DEM Use

Grid Space	Scale of Map	Use Purpose	User Group
2m - 3m	1:1,000	Map Production Detail Design for Civil Eng. Cell Planning Sight Visibility Analysis	Map Production Company Engineering Consultant Cellular Phone Company Military Agency
5m - 10m	1:5,000	Basic Design for Civil Eng. Map Production Landscape Architecture Environmental Management Agriculture Sight Visibility Analysis	Engineering Consultant Map Production Company Engineering Consultant Government Farmer Military Agency
25m - 50m	1:25,000	Topographic Modeling Environmental Management Sight Visibility Analysis	Government Geographer, Geologist Military Agency

2.2 The Standard of DEM in Korea

(1) What is the preferable model for Korean DEM?

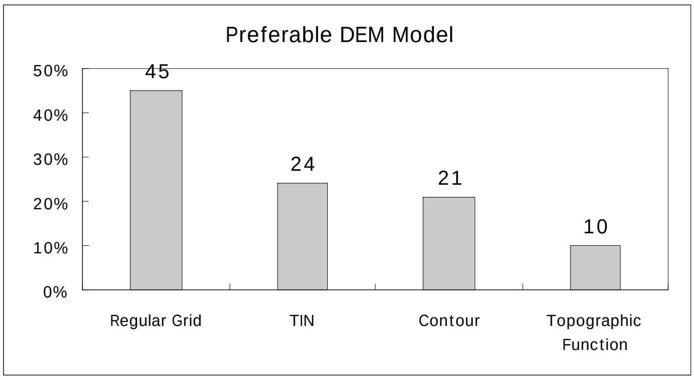


Fig. 4 Recommended Model for Korean DEM

(2) Do you like the grid space is unique all over the country or variable depends on the geography?

About 79% people who answered want variable grid space of DEM depend on the site conditions.

(3) What is the proper grid space if Korea makes a regular grid DEM?

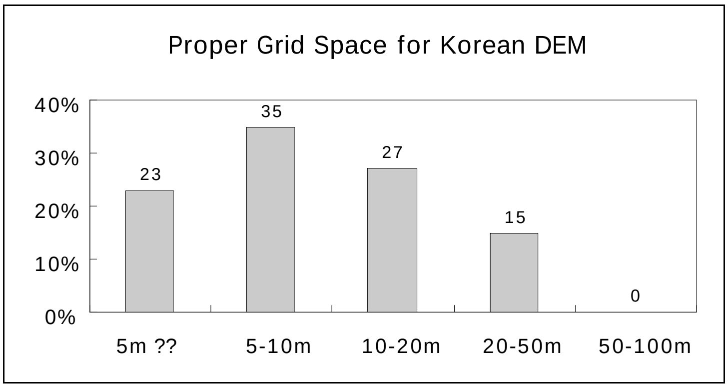


Fig. 5 Recommend Grid Space for Korean DEM

(4) What is the proper production method for Korean DEM?

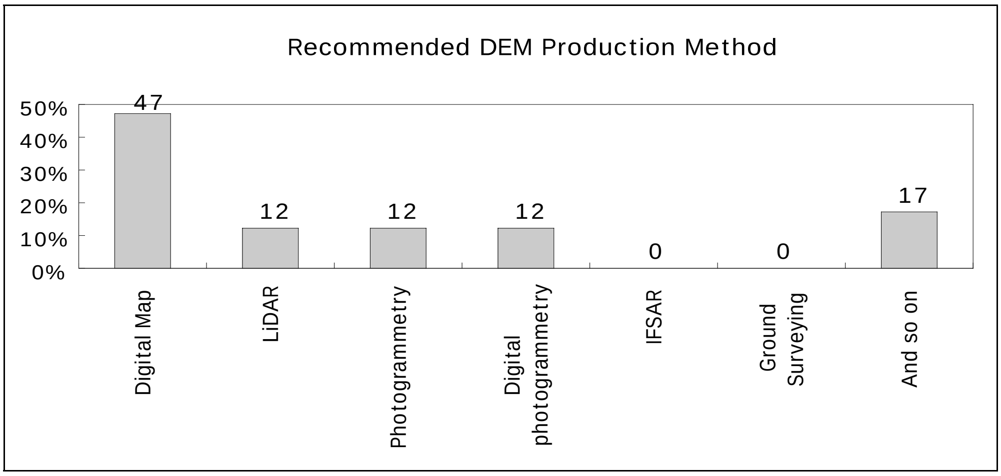


Fig. 6 Recommended Production Method for Korean DEM

3. Pilot DEM Production

3.1 Test Site

The test site is located in Chungju, Chungbuk in Korea. The site offers a cross section of terrain and land cover types. The area includes an urban region, a hill region and mountainous region. The test site is 3 sheets of topographic map in extent shown in Fig. 7. Each topographic map (scale 1:5,000) covers 1.5'N_1.5'E area.

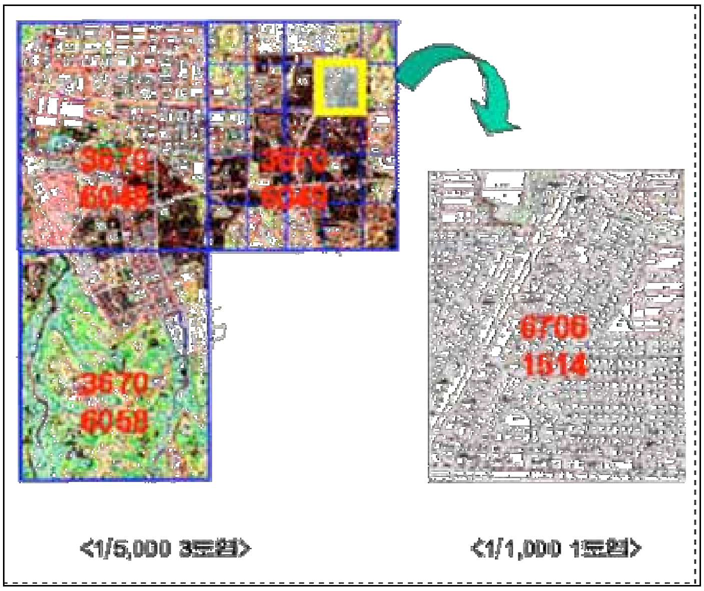


Fig. 7 Test Site for Pilot DEM Production

3.2 Production methods

In order to investigate the quality, the technical efficiency and production cost, a tentative regular grid DEM in a small region was generated based on the conventional technology, interpolation based on the elevation data in digital topographic maps (original paper map scale 1:5,000), elevation extraction using analytical plotter and digital plotter. The regular grid DEM on the test site was also produced using a new technology, LIDAR.

1) DEM production from digital topographic map

A cost effective method for producing DEM is interpolating grid elevation from contours and spot heights on digital topographic map. National Geographic Information Institute (NGII), Korea, has digital topographic maps which were digitized from paper topographic maps drawn on scale 1;1,000, 1:5,000 and 1:50,000. In this study, we used digital topographic maps at scale of 1:5,000 and 1:1,000. Kriging algorithm in Arc/Info (ESRI) was used to interpolate elevations of grid from elevation information in digital topographic map. Below is the entire process to produce DEM from digital topographic maps.

Digital Topographic Map	–	Extract Elevation Information	–	Supplement Breaklines	–	Interpolation	–	DEM
scale 1:5,000 1:1,000		contour, spot height		hydrography, roads, ridges		Kriging		grid 10m_10m grid 5m _ 5m

Fig. 8 Process for DEM Production from Digital Topographic Map

2) DEM production by Analytical Plotter

DEM (grid 10m_10m) was produced by analytical plotter, P1 and Anagraphe. Its process is shown in Fig. 9.

Aerial Photo	GCP Surveying	Orientation	Extract DEM (DTM Module)	DEM
Scale 1:20,000 1:5,000	PlaneCP:13Points B.M. :17Points	No. of Model:8 :4	Parallel Section Method (DXF)	grid 10m_10m (ASCII)

Fig. 9 Process for DEM Production by Analytical Plotter

3) DEM production by Digital Plotter

DEM (grid 10m_10m) was produced by digital plotter, ImageStation(Intergraph). The process is shown in Fig. 10.

Scan Image (Aerial photo)	Orientation	Extract Elevation Points	Enhance Elevation Data	Production DEM
Scale 1:20,000 1:5,000	Image Matching	Elevation Block	Model Boundary Shaded Area	Interpolation (Kriging)

Fig. 10 Process for DEM Production by Digital Plotter

4) DEM production by LiDAR

LiDAR stands for Light Detection And Ranging. In a nutshell, light detection and ranging is the science of using a laser to measure distance to specific points. In contrast to conventional technologies, it is possible to process data automatically. Because it is active sensor, it measures distances irrespective of weather. It is favorable to produce DEM in the forest and urban area where shade covers the bald earth. The accuracy reported by the manufacturer for the LiDAR is 15cm vertical RMSE, and 30cm horizontal RMSE.
The airborne LiDAR system consisted of a LiDAR (ALTM1020 System, Optec Inc.) and a GPS (Trimble 4700) equipped in an airplane (Piper). The flight plan is shown in Table. 2, The interval between plight line was 50m..

Table. 2 Flight Plan for Pilot DEM Production

Flying Altitude	Velocity	Pulse Repetition Rate	Sidelap	Scan Width	No. of Path
1,000 m ASL	180 km/h	5,000 Hz	87 %	450 m	100 lines

After obtain raw LiDAR data , those was processed through below procedure.
_ Correct horizontal position of flight paths based on significant points.

_ Correct vertical error based on leveling data on straight line region

_ Supplement breaklines including roads, rivers, valley and ridges

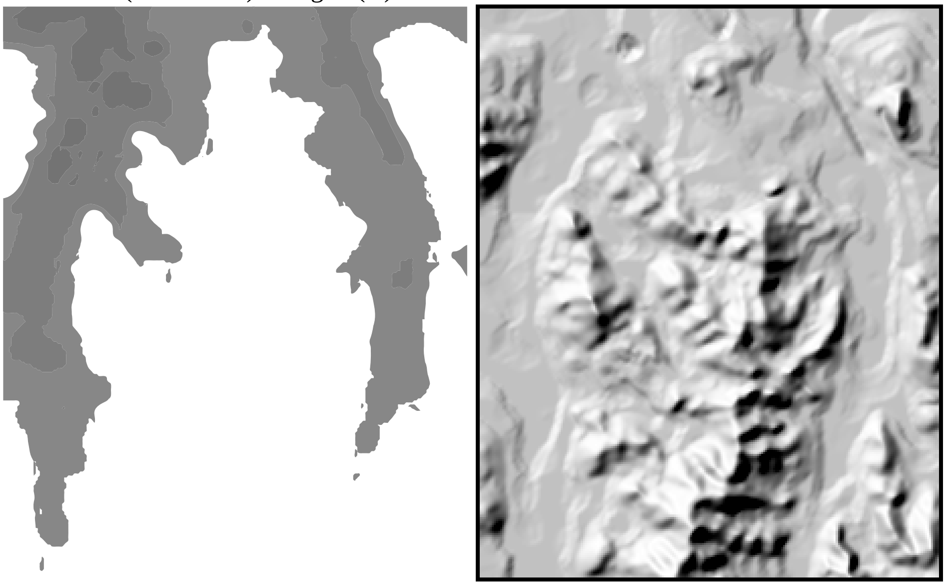
_ Extract and remove manmade structure and forest canopy

_ Interpolation by Kriging

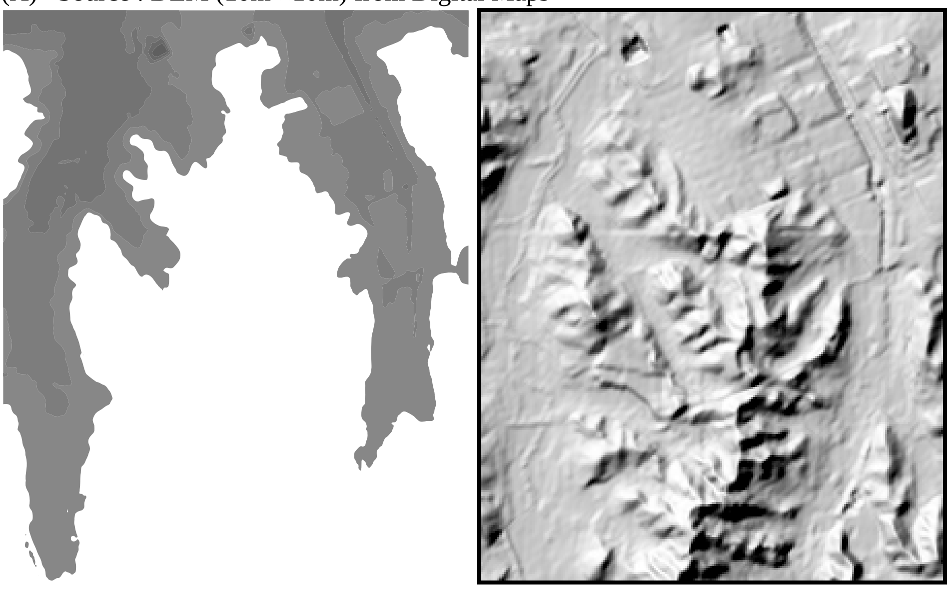
3.3 Contour Maps and Shaded Relief Maps of the Pilot DEMs

There are many ways to verify the confidence of DEMs. The easy way is to examine contour maps (or shaded relief maps) drawn using the DEMs with the unaided eye. Fig. 11 includes contours maps (contour interval : 5m) and shaded relief maps drawn using the pilot DEMs (grid space : 10m ×10m or 5m ×5m) produced by above 4 methods. As shown in Fig. 11(A), the contours and shaded relief maps drawn using

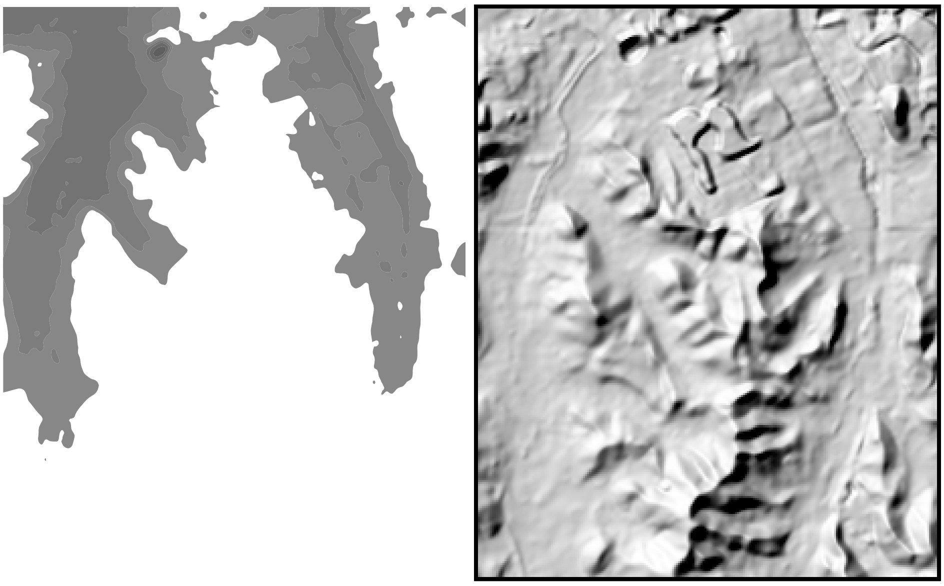
DEMs from digital maps feels dull compared to others(Fig. 11(B), (C), (D) and (E)). In Fig. 11(C), we can readily see a rising ground looks like an alphabet character ‘n’ in upper central region of the test site. Maybe there are some errors in the central upper region of the DEMs from aerial photographs with digital plotter. On the other hand, we can see a road from northwest to southeast located in central region of the test site on the DEM from LiDAR(Fig. 11(D) and (E)). The road was not seen on other shaded relief maps. Because LiDAR acquired height data to produce the pilot DEMs, it provided more current height information than the others in this test. It is obvious that the resolution of DEMs plays an important role in drawing contours and shaded relief maps. The roads, rivers, and ridgelines on shaded relief maps drawn from DEM(5m ×5m) in Fig 11(E) are sharper and clearer than those of shaded relief maps drawn from DEM (10m ×10m) in Fig 11(D)



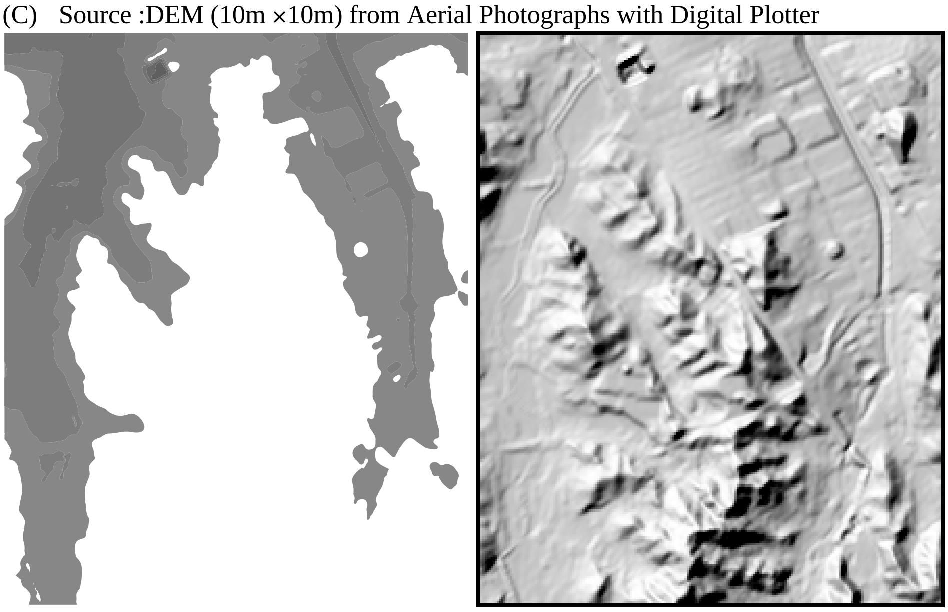
(A) Source : DEM (10m ×10m) from Digital Maps



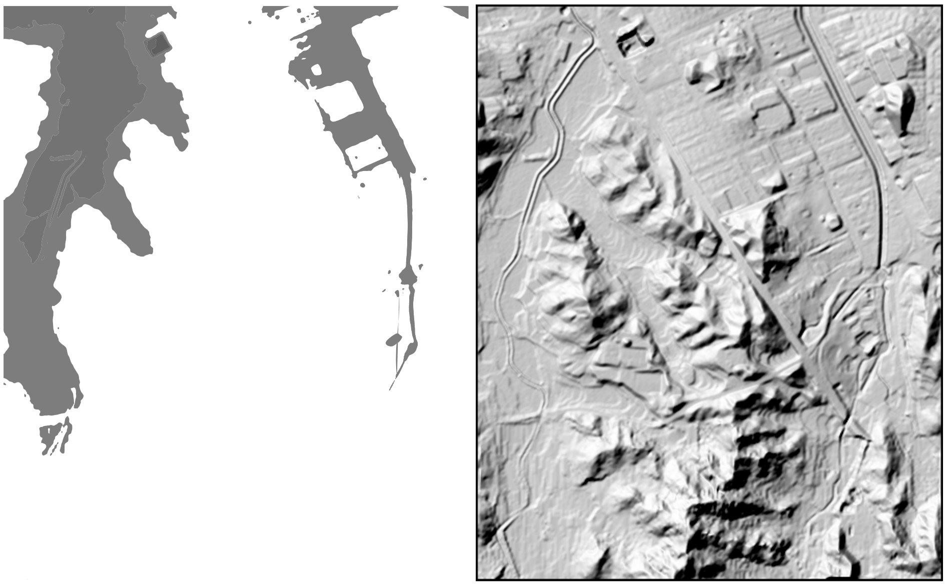
(B) Source : DEM (10m ×10m) from Aerial Photographs with Analytical Plotter



(C) Source :DEM (10m ×10m) from Aerial Photographs with Digital Plotter



(D) Source : DEM (10m ×10m) from LiDAR



(E) Source : DEM (5m ×5m) from LiDAR

Fig. 11. Contours and Shaded Relief Maps Drawn using the Pilot DEMs

3.4 Accuracy of the Pilot DEM on Test Site

In 1998, The FGDC, USA, published new Geospatial Position Accuracy Standards in support of the National Spatial Data Infrastructure (NSDI). Part 3(FGDC, 1998), the National Standard for Spatial Data Accuracy (NSSDA), provides the following vertical accuracy statistics.

$$RMSE_Z = \sqrt{\frac{(Z_{data\ i} - Z_{check\ i})^2}{n}} \qquad (1)$$

where Zdata i is the elevation of the ith check point in the dataset

Zcheck i is the elevation of the ith check point in the independent source of higher accuracy

n is the number of points being checked.

The following graphs show RMSEz related to DEM production method and test sites. RMSEz of DEM produced by LiDAR was smaller than any other case. In this case, Zcheck i is elevation of 27 check points surveyed by DGPS. But, DEM grid space between 10m and 5m did not affect its RMSEz in this study as shown in Fig. 11. On the other hand, DEM produced by analytical plotter shows smaller RMSEz in test site as shown in Fig. 12. In this case, Zcheck i is DEM produced by LiDAR.

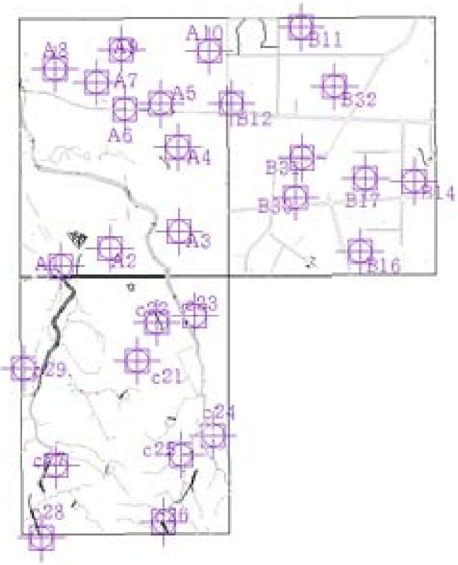


Fig. 12. Distribution of Check Points on the Test Site

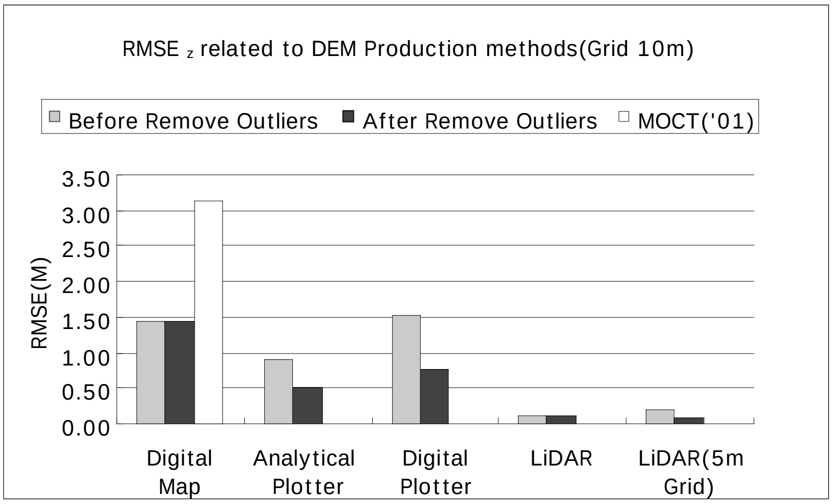


Fig. 11 RMSEz related to DEM Production Method (Grid 10m)

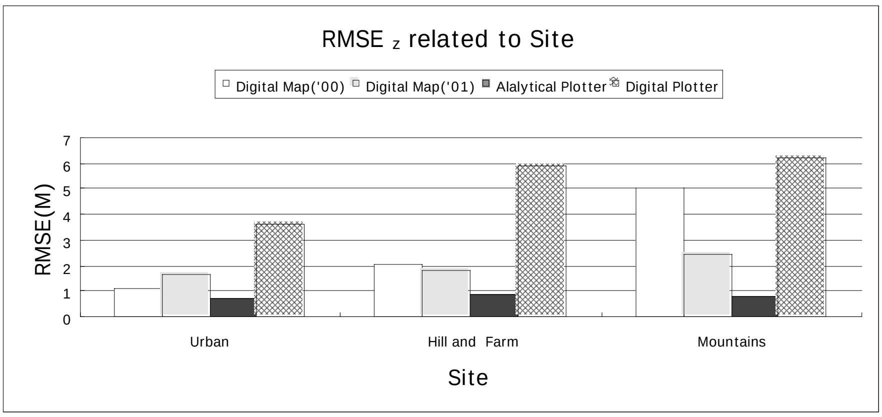


Fig. 12 RMSEz related to Site(Grid 10m)

4. Investigation of the Pilot DEM Production

4.1 Resolution

1) Applications

DEM could be used to correct geometric error of satellite image. It could be used to draw contours in topographic map. DEM is also used in design of civil engineering field and prevention of disaster and environmental management. So it is need to investigate what resolution is proper to specific applications.
For the first purpose, correction for satellite image, it is enough if the grid spacing is same to the resolution of satellite image or denser than it. The resolutions of satellite image are 30m (Landsat TM), 10m (SPOT), 6.6m (Arirang EOC) and 1m(IKONOS). So the grid spacing should be from 1m to 10m. However the appropriate grid space for the Korean DEM is from 5m to 10, because the resolution Arirang EOC is 6.6m. For the second purpose, design of civil engineering, prevention of disaster and environmental management, the appropriate grid spacing of DEM is from 3m to 10m.

2) Production Technology

LiDAR can produce DEM with 1m grid space or denser than 1m grid space. And we can maintain its vertical accuracy(RMSEz) within 0.15m. On the other hand, analytical plotter can produce DEM with 1m resolution using the photo scale of 1:5000. In this case, we can maintain its vertical accuracy 0.3m. In the case of digital plotter and satellite image, the maximum grid space of DEM is same to the resolution of the image. Among the DEM production technology available, the LiDAR method was preferred to the others because it could maintain high vertical accuracy with automatic data processing.

4.2 Accuracy

According to the regulations of NMAS, NSSDA and ASORS, it turned out that height errors(RMSEz) of contour line in topographic map at scale of 1:5,000 (contour line interval : 5m) were 1.67m (contour interval / 3) in case of clear height points and 0.83m (contour interval / 6) in case of general height point s in Korea
Therefore, if DEM could be used to draw 5m contour of topographic map(scale 1:5,000), its appropriate RMSEz range is 0.83m_1.67m. According to same reason, 10m interval contour of topographic map (scale 1:25,000) could be drew using DEM which its RMSEz is 1.67m_3.33m.
In the test area, 10m grid space DEM was produced using digital map, analytical plotter, digital plotter and LiDAR. And the RMSEz on the check point showed smaller than 1.5m. It is good results. Referring to pilot DEM production in this study, "Digital Map Production Regulations" in Korea and the cases in USA, the attainable RMSEz of DEM produced by various methods could be derived as shown in Table 3. So, we could draw contour line of digital maps in scale of 1:5000 maps by DEMs which were produced by digital map (scale 1:1,000), analytical plotter and LiDAR.

Table 3. Attainable RMSEz of DEM related to its Production Method and Use

Methods	Source data	Site	RMSE	Reference

Digital Map	scale 1:1,000 contour interval: 1m	Urban	1.89m	MOCT('01), grid size 10m
			1.12m	NGII('02), grid size 5m
	scale 1:5,000 contour interval: 5m	Urban	1.65m	NGII('02), grid size 5m, 10m
		Field	1.79m	NGII('02), grid size 5m, 10m
			1.87m	MOCT('01), grid size 10m
		mountain	2.47m	NGII('02), grid size 5m, 10m
			5.06m**	MOCT('01), grid size 10m
Analytical Plotter	photo scale 1:5,000	urban	0.33m	NGII('02), grid size 1m
		Field	N/A	N/A
		mountain	N/A	N/A
	photo scale 1:20,000	Urban	0.68m	NGII('02), grid size 10m
		Field	0.83m	NGII('02), grid size 10m
		mountain	0.81m	NGII('02), grid size 10m
Digital Plotter	photo scale 1:5,000	Urban	5.37m	NGII('02), grid size 1m
	photo scale 1:20,000	Urban	3.63m	NGII('02), grid size 10m
		Field	5.91m	NGII('02), grid size 10m
		mountain	6.25m	NGII('02), grid size 10m
LiDAR	ALTM1020(2MHz)	Urban, Field, Mountain	0.15m	FEMA

4.3 Production Cost

The cost of DEM production for a 1:5,000 map sheet(6.2_) was estimated based on the pilot production as shown in Table 4. The cost of DEM production using Digital Map is lower than any other methods. The cost of DEM production by LiDAR and Plotter is similar. It is expected that the cost of LiDAR will be cut with the user grows.

Table 4. Cost Estimation for DEM production in Korea (per 6.2_ area)

Production Methods	Estimated Cost		Remarks
	5m DEM	10m DEM	
LiDAR	_5,690,000	_2,276,000	Assumed basic area 1,000 _
Analytical Plotter	_11,247,000	_2,962,000	Including fee of Aerial Photographing, GCP Survey
Digital Plotter	_3,320,000	_3,196,000	Including fee of Aerial Photographing, GCP Survey, Scanning
Digital Map	_151,000	_139,000	Source Digital Map 1:5,000

5. Conclusions

As a result of this study, the following conclusions were derived through the questionnaire and pilot DEM production.

1) Most of the expecting users want regular grid model. The preferable grid space is 5m or 10m.

2) Among 4 DEM production methods tested, LiDAR was regarded as the best DEM production method because its RMSE is small, 0.1m. While its data could be processed automatically to produce DEM, its cost is reasonable.

3) The demanding RMSEz of DEM for drawing 5m contour in scale of 1:5000 digital map is 0.83m~1.67m. Two methods, analytical photogrammetry and LiDAR, could satisfy the accuracy requirement. However, the analytical photogrammetry method demands much more cost compared to LiDAR. Therefore, LiDAR is recommended as a most suitable Korean DEM production method.

4) Considering its use and cost, it was proposed 5m grid space in urban area and 10m grid space in the other area for Korean DEM.

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