Development and Utilization of High Precision Digital Elevation Data taken by Airborne Laser Scanner

Osamu AKUTSU, Masataka OHTA, Tamio ISOBE
Hisamitsu ANDO, Takahiro NOGUCHI and Masayuki SHIMIZU

Abstract

Disasters caused by heavy rain in urban areas bring a damage such as chaos in the road and railway transport systems, power failure, breakdown of the telephone system and submersion of built up areas, subways and underground shopping arcades etc.

It is important to obtain high precision elevation data which shows the detailed landform because a slight height difference affects damages by flood very considerably. Therefore, the Geographical Survey Institute (GSI) is preparing 5 m grid digital terrain model(DTM) based on precise ground elevation data taken by using airborne laser scanner.

This paper describes the process and an example of the use of a 5 m grid digital data set.

1. Introduction

GSI publishes “Digital map 10 m grid (elevation of volcanic area) ” , “Digital map 50 m grid (elevation) ” , ”Digital map 250 m grid (elevation) ” as digital map data. These are made from the contour line of basic map of volcano of 1/5,000 , 1/10,000 and the contour line of the 1/25,000 topographical map.

However, there has been a considerable demand for more detailed elevation data. Fortunately, with the advent of improved measurement technologies, these have become more freely available. One of the technologies is airborne laser scanning.

GSI began publishing a “Digital map of 5 m grid (elevation)” from June, 2003, as a basic resource for disaster prevention, land protection and land use planning in the government and the private sector.

2. Airborne Laser Scanning

Airborne Laser Scanning is an active measurement method in which the distance from the sensor to the ground is measured by processing the laser beam emitted from the onboard scanner and reflected on the ground. Aircraft positions are calculated using a combination of GPS data, both on the aircraft and on the ground. Aircraft acceleration and three-axial attitude (ω,φ,κ) data measured by an IMU(Inertial Measurement Unit) are also used for the calculation. Furthermore, the direction data of the laser beams are measured by an onboard sensor. These data are combined to calculate the three-dimen-sional position (X, Y, Z) on the ground (Fig. 1).

3. Preparation of the 5 m grid digital elevation model

Preparation of the 5 m grid digital elevation model is implemented as in Fig. 10 (work process flow). In the following, each step is explained based on the actual work implemented in the Saitama and Tokyo areas.

3.1 Ground data acquisition process

3.1.1 Planning

In order to measure data appropriately, a measurement plan, including necessary equipment and materials, must be prepared. Especially important at this stage of the planning are the specifications of the laser measurement system. These include measurement density, the flight course for efficient measurement, location of the airport, weather and arrangement of GPS (Global Positioning System).

3.1.2 Airborne Laser Scanning and Digital image acquisition

Based on parameters established in the planning, airborne laser scanning is conducted. Fig. 2 shows the areas where airborne laser scanning was carried out. The parameters shown in Table 1 were used for south-eastern part of Saitama and the eastern part of Tokyo.

Distance data, onboard GPS data and the posture data of the airplane (ω,φ,κ) by IMU are recorded onto a hard disk and PC card. At the same time as laser scanning, stereo digital (monochrome) photos are taken by an onboard digital camera. GPS measurement is also done at the ground GPS base station during laser scanning.

3.2 Verification of Accuracy

3.2.1 Rate of "No data"

In this work, if the measurement point did not exist in a 2.5 m * 2.5 m grid cell, that cell was given the value of "No data". The number of grid cells with "No data" is calculated for the area of 2.0 km * 1.5 km corresponding to the map sheet of National base map of 1/2,500 scale. This rate must be <10%. If it exceeds 10%, remeasurement must be done, depending on the cause.

Water surfaces and black roofs are the major reasons for "No data" because they absorb the laser beam.

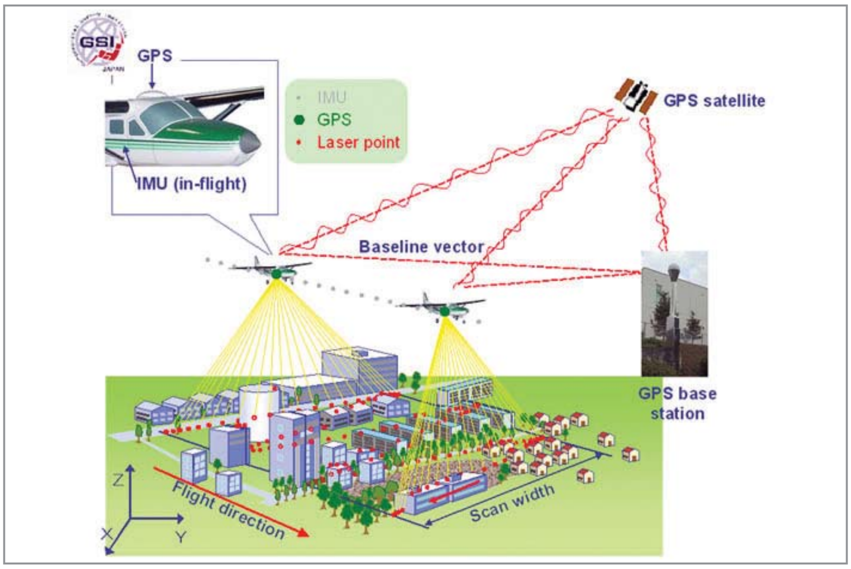


Fig. 1 Image of Airborne Laser Scanning

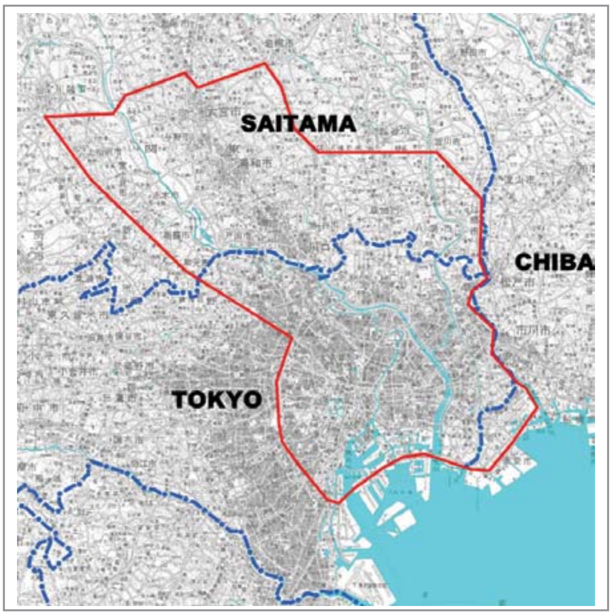


Fig. 2 The study area (South-East of Saitama)

Table 1 Measurement Specification

Laser Scanner	Flying altitude	2,500 m
	Pulse rate	24,000 Hz
	Scan rate	24 Hz
	Scan angle	±10°
	Swath width	881 m
	Flight Speed	203.7 km/h（110 knot）
	Beam	0.3 mrad
	Course interval	400 m
	Course overlap	54.6 %
	Measurement point interval	2.4 m（along-track）
		1.8 m（cross）
IMU	Time record	200 Hz

3.2.2 Side-lap comparison

The data taken along any given course are to overlap about 30 % with those of adjacent courses. Data in the overlap area are compared to confirm data quality. The method of verifying is to select a wide, flat area in the overlap part, and then to set up a square of 50 m * 50m. The height difference for every grid of 1m interval within the square is then computed. Finally, an average and a standard deviation from the differences are calculated. The results are presented in histogram form.

3.2.3 Comparison at verification points

In order to verify the accuracy of measured points, twenty sites were chosen from the target measurement area and coordinates of two points per site surveyed by GPS and fourth class leveling were performed.

3.3 Processing of Digital data

3.3.1 Measurement data processing

The GPS satellite data and IMU data which were measured on the airplane and the GPS satellite data measured at the ground GPS base station are analyzed with special software, and an exact 3-dimensional position and inclination of the airplane are computed.

Next, by using the exact 3-dimensional position of an airplane and inclination, and the distance data measured by laser scanning, the Transverse Mercator coordinates and the altitude of every measurement point are computed with special software. The Geoid 96 model is taken into consideration for calculation of altitude.

3.3.2 Ground image (Orthophoto)

Monochromatic digital photos which are taken simultaneously with laser measurement are reconstituted in a digital analytical stereo plotter, and a digital monochromatic ortho image is created using the 3-dimensional position, inclination data, and 3-dimensional terrain data obtained from the stereo model.

In addition, Georeference information on the ortho image is created.

3.3.3 5 m Grid data

After removing noise, the digital data acquired by Airborne Laser Scanning are divided into tile units based on the 1/2,500 national base map sheet. These data are called original data, (This is also called Digital Surface Model: DSM). It is worth noting that surface features such as buildings and trees are contained in the original data.

Automatic filtration, which identifies the objects listed in Table 2, is applied to the original data. Accordingly, the results are divided into two data groups: those capturing the earth ground surface and those capturing the surface of objects which are off the ground. These data are called temporal ground data.

In order to check the temporal ground data, the TIN model generated from temporal ground data is overlaid on the ortho image and is checked visually to see whether the temporal ground data is appropriate or not. When an error is found, it is corrected manually on the display. After checking the temporal ground data in this way, data identified as ground surface (ground data) are extracted.

An irregular triangular network (TIN) is generated from ground data, and DTM of 5 m grid is created. Furthermore, this DTM is filed for the area covered by a 1/2,500 national base map sheet as a unit, and is saved in CSV (Comma Separated Value) format.

In the following, the technique of automatic filtering is briefly described.

● Filtering Process

Filtering is applied to detect and remove objects which are not parts of the ground surface such as buildings, bridges, trees, cars and humans. The principle of filtering is as follows: First, a small window is set and the distribution of height difference among the points within it, are calculated. Points whose height differences are larger than some threshold are regarded as non-ground surface points. By this process, the edge of the non-ground surface is detected. When the window is completely included in such a non-ground surface object, all points in the window might be regarded as points on ground surface. In such a case, considering results from neighboring points, correct decisions are made.

Depending on the object it is required to detect, the window size and threshold must be decided. Usually, windows for tall buildings, medium height buildings, low buildings/trees, and small objects are prepared and thresholds are decided respectively. Figure 3 shows how filtering works for several objects.

Finally, only points which are not regarded as non-ground surface points are extracted. The surface generated by these points is regarded as the ground surface.

3.3.4 Water Polygon

Water polygons, representing the water surface of rivers and the ocean, are generated using ortho images because measurement accuracy is reduced by absorption and diffuse reflection of the laser beam by water.

The target rivers, lakes and oceans used to create water polygons are classified by the following criteria.

- Rivers are defined as having a width of 10 m or more; ponds exceed 10 m * 10 m, but exclude pool and sewage disposal facilities.
- As the width of a river changes according to its location, it must be decided case by case whether it can be regarded as a river of 10 m width or more. If stretches of the waterway in which the width exceeds 10 m dominate, it is regarded as a river.
- Small-scale sandbanks are not included.
- Planimetric features such as water gates are not included.

3.3.5 Ground surface attribute

After checking whether each 5 m * 5 m grid cell includes a point in the ground data, or it is contained in a water polygon, an attribute value is assigned to each cell (ground data exists: 1, does not exist: 0, in water polygons: -9999).

The method of preparing the ground surface attribute file is as follows: First, a 2.5 m mesh is assigned to each file covering the area corresponding to the 1/2,500 national base map sheet, and a value (0) is set as initial value. The value (1) is put in the mesh which includes ground data. When data is exactly on the boundary of the mesh, the data is regarded as included in the mesh right side or upper side. When the center of the mesh is included in a water polygon, the value (-9999) is placed in the grid. Finally, from the 5 m grid attribute file the 2.5 m grid attribute file is created.

4. Verification of data quality

Data quality was checked using the data taken for the area in Fig. 2.

4.1 Rate of “No data”

Based on the information placed in each grid cell the “No data” rate was calculated. The number of the “No data” grids was 5,820, 404, which corresponds to 4.76 % of the total number of the grid (2.5*2.5) : 122,326,431. On the whole, the “No data” rate is small and it can be concluded that good data were acquired.

It should be added that areas where the “No data” rate was large include water surfaces such as a large river.

4.2 Side-lap comparison

Since the difference of elevation at the course overlap is 4.5 cm or less on the average, it is judged that there is no inclination (roll) in each course, and good data were acquired for each course (mouth-of Arakawa-river area).

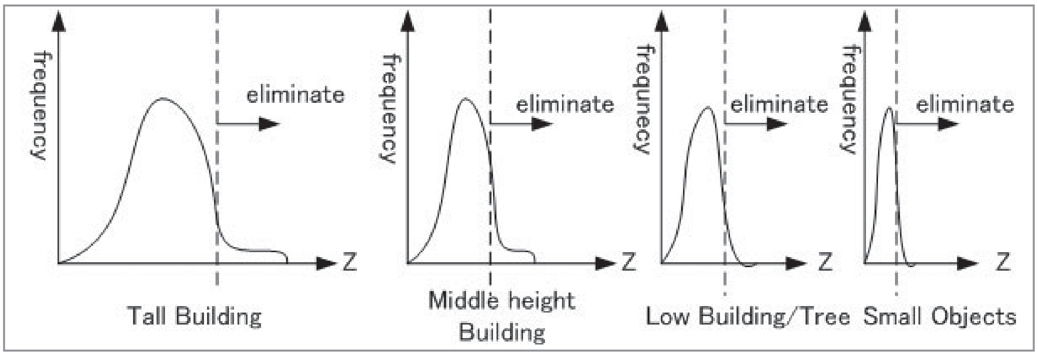
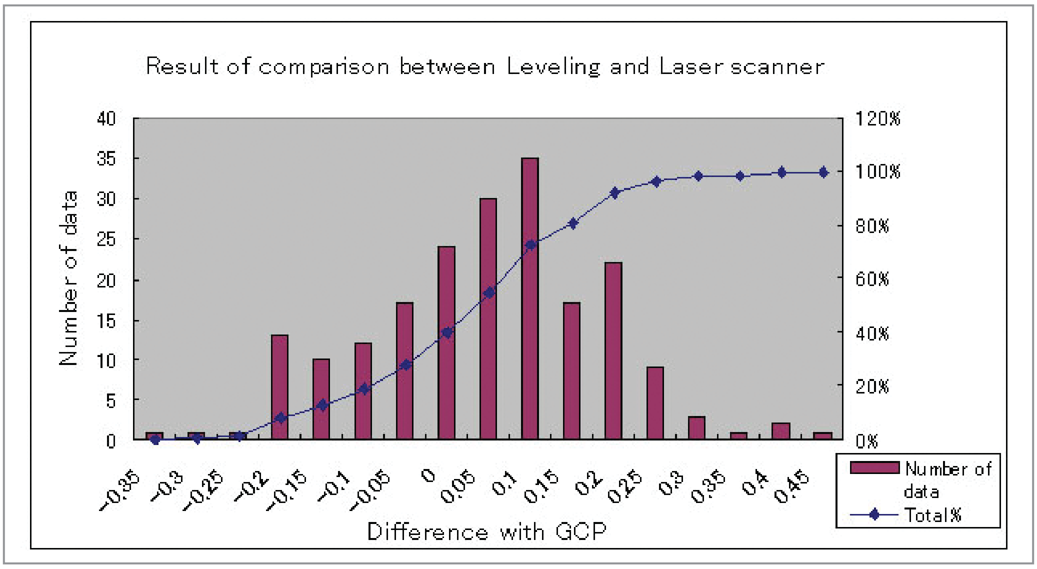


Fig. 3 The filtering using statistical method

Table 2 Verification of Accuracy



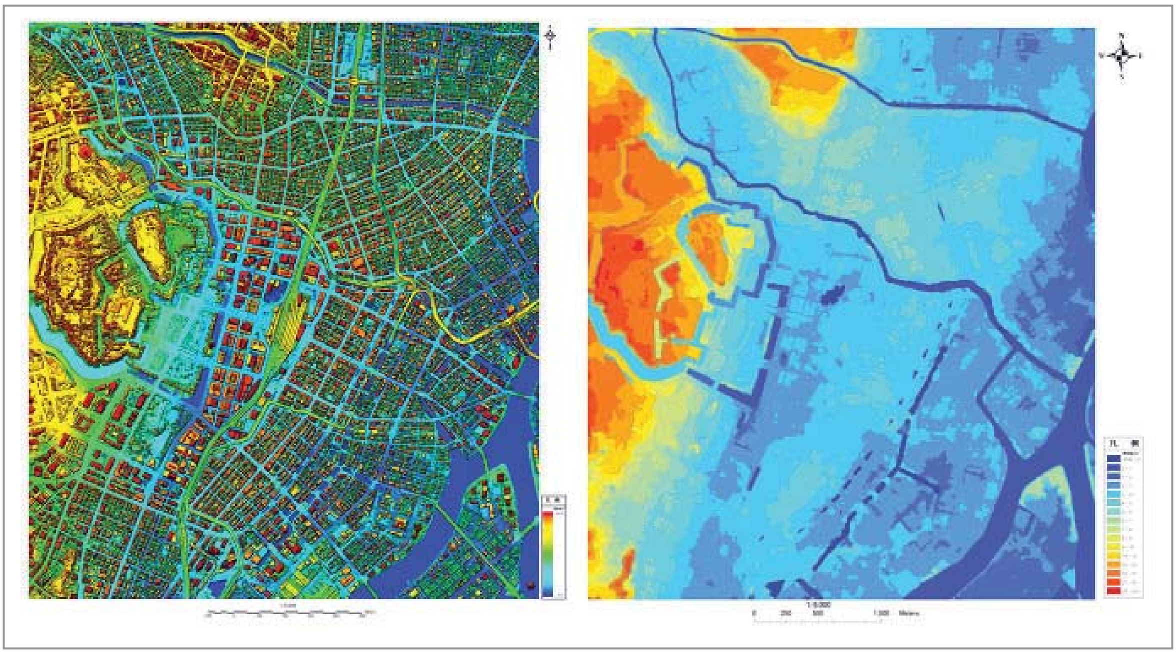


Fig. 4 Original data (DSM) and 5m Grid data (DTM)

4.3 Comparison of verification points

The sites which were selected as points for accuracy verification were flat ground surfaces such as parks. Coordinates of verification points acquired by airborne laser scanning were compared with those derived from the ground survey using GPS and leveling.
The result of comparison with the altitude value of leveling, is 0.03 m on average (maximum +0.42 m minimum value-0.32 m) and the standard deviation is 0.16 m (Table 2 south-eastern part of Saitama).

5. Comparison with other data

5.1 Comparison with 50 m grid (elevation)

Fig. 5 shows a comparison of a 5 m grid color-gradation map and a 50 m gird color-gradation map of Toda-city and the Itabashi-ward area in the Arakawa lowlands. The difference is clear in the landform of the lowland part. Although a river and a bank can be distinguished in the 5 m grid, it cannot be distinguished in the 50 m grid. Since the 50 m grid acquires data from the 1/25000 scale topographical map, no data from a river and a bank, are present. The form of a tableland also shows large differences.

5.2 Comparison with Land Condition Map

Fig. 6 shows a comparison between the 5 m grid color-gradation map and a land condition map. The river which flows through the center is the Arakawa. A bank can be distinguished clearly.

In the left figure (5 m grid (elevation)), the right yellow-colored portion is the Omiya tableland. The old river road and the natural bank of Arakawa in Saitama-city can be identified in the upper part of Fig. 6.

The river flowing around lower left corner is the Shinkawagishigawa. The river plain of Arakawa, at present, is used as a paddy field and a playground.

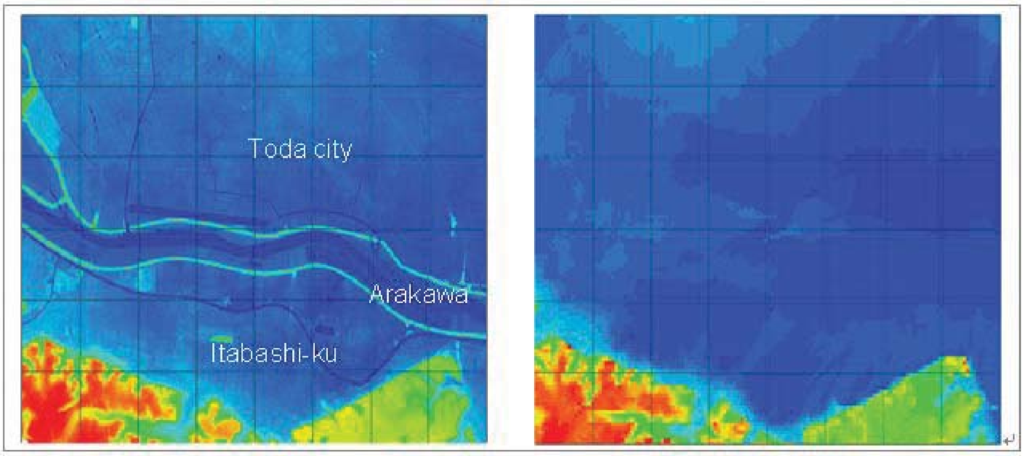


Fig. 5 Comparison of digital map 5 m grid (elevation) and digital map 50 m grid (Northern Tokyo)

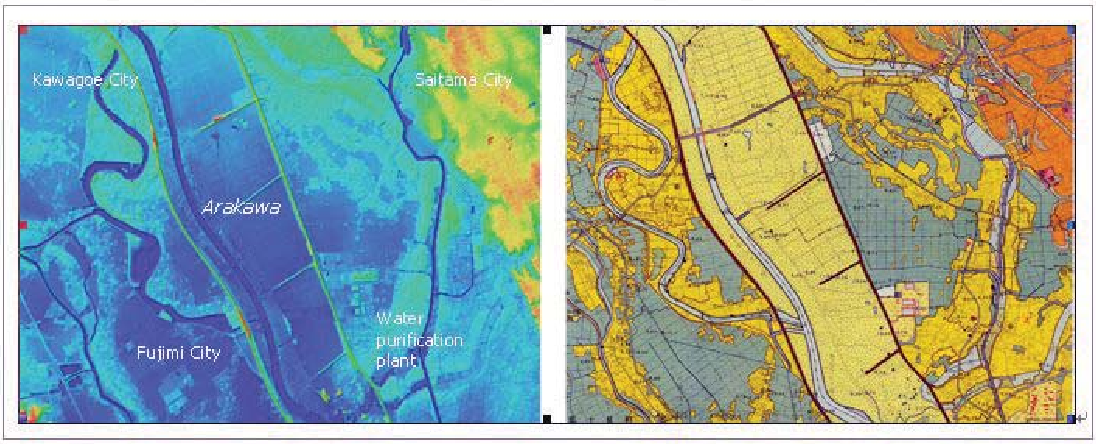


Fig. 6 Comparison of digital map 5 m grid (elevation) and Land Condition map (Saitama City)

6. Data utilization

The following are examples how the 5 m DTM is used.

- Relief map, Bird's-eye view map, CG (computer graphics) expression・・・

Fig. 7 is a relief map created from data obtained by airborne laser scanning after application of filtering. It shows the Nihon land amusement park on the southeast slope of Mt. Fuji.

This relief map is artificially shaded using the effect of light cast to the terrain model of the area so that it appears three-dimensional.

On the relief map, detailed geographical features (wrinkles, unevenness), the situation of lava flows and its boundary can be distinguished. Moreover, distinguishing landforms near the center of the image which look like valleys and embankments, are present. The parts of the landforms, like valleys, which look black, are crack craters.

In aerial photo interpretation, the detailed geographical feature accompanied by volcanic activity or peculiar to a volcano sometimes cannot be identified in a forest area. However, by expressing the data which are removed planimetric features from the data obtained by airborne laser scanning in three dimensions, it becomes possible to identify the original volcanic geographical feature. In this way, new craters might be confirmed after field reconnaissance survey.

- 3-dimensional expression of a townscape, and for environmental purpose. (Fig. 8)
- Application to various simulations, such as a flood simulation etc. (Fig. 9)
- Basic data for hazard map creation

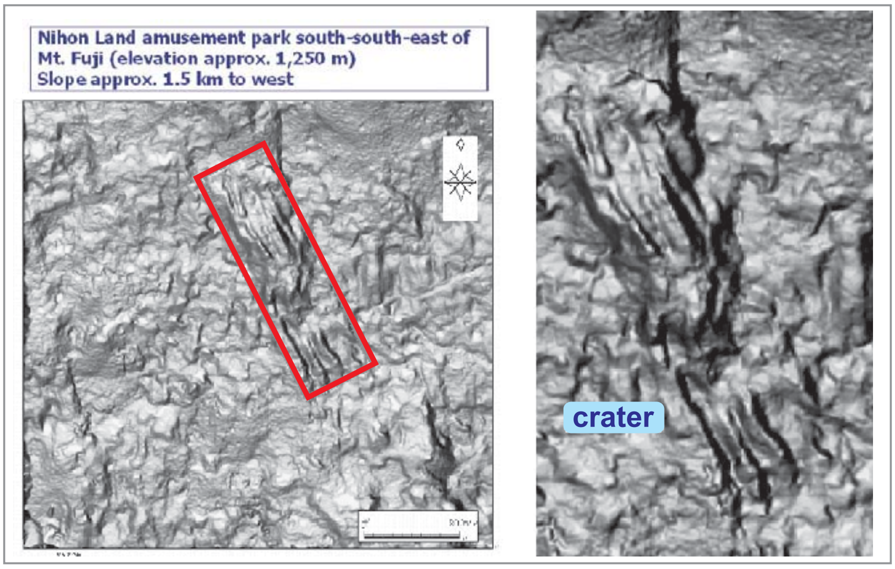


Fig. 7 Relief image（south-east slope of Mt. Fuji）

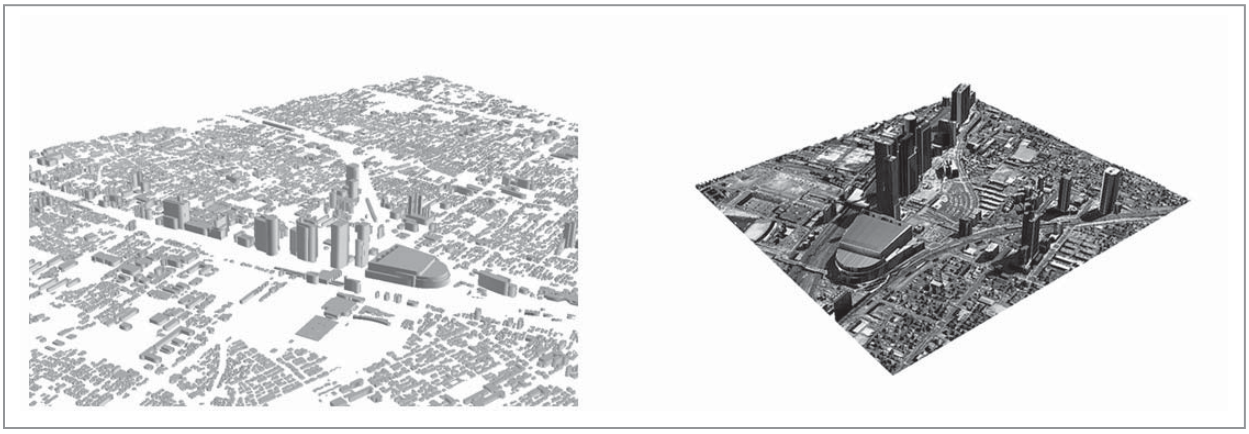


Fig. 8 3D image（Saitama new downtown）

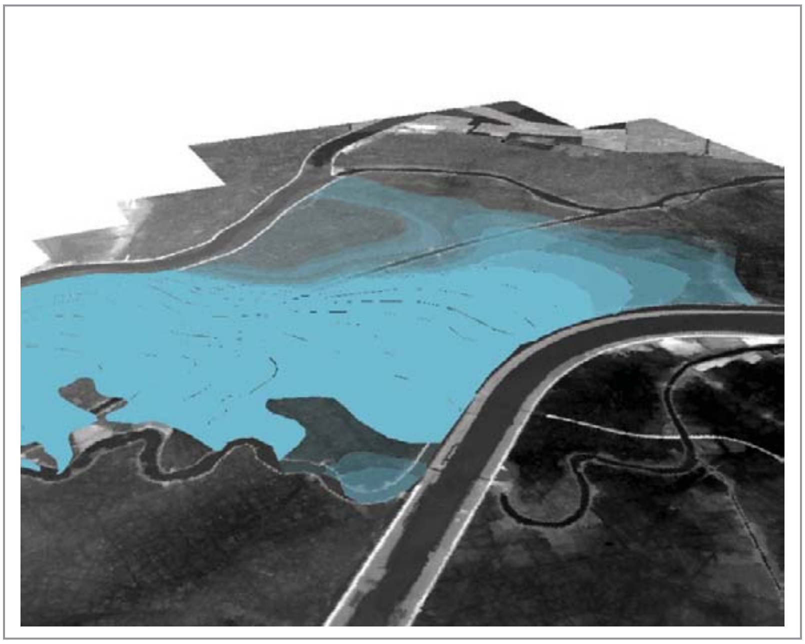


Fig. 9 Flood simulation (Typhoon Kathleen)

7. Data development and future issues to be solved

Presently, the 5m grid (elevation) data development is as follows.

- Saitama (483 km^2) : Published (June, 2003)
- Tokyo (834 km^2) : Published (December, 2003)
- Nagoya (522 km^2) : Published (March,2005)
- Kyoto (111 km^2) : Published (March,2006)
- Osaka (528 km^2) : Published (March,2006)
- Hakata (198 km^2) : Published (March,2006)
- Coastal area (2,000 km^2) : under development

There are several issues still to be solved

● Data within water area

Height should be incorporated into the grids in water parts, in order to use it for flood simulation.

● Planimetric features to delete

In this work, although the planimetric features to be removed were determined, as basic data for a flood simulation this determination is not perfect. It will be necessary to collaborate closely with the organizations performing river flood analysis in order to decide which objects can be most sensibly removed. Moreover, since the data created in this work can be used for other purposes besides flood analysis, we need to determine which planimetric features are to be removed in order for the data to be more widely applied in other issues and situations.

● Check of planimetric features not clear

During the implementation of this work there were some cases in which the data expressed by the dense contour line (which means taller objects than their neighbors) can not be distinguished even if orthophoto and the other data are used. Therefore, it is better to perform a field survey whenever needed. For example, in cases in which geographical features are likely to undergo change, it is desirable to perform field surveys for checking. Such cases include construction sites and measurements after which some time has passed.

8. Conclusion

The airborne laser scanning technique is utilized in various fields to acquire basic data not only of flood simulations but also of various simulations such as views, landslides, electric wave propagation analysis, city planning and CG (computer graphics), In addition, it clearly has the potential to expand into other applied fields.

Reference

GSI (Geographical Survey Institute) (2004)
Work regulations on producing "Digital map 5 m grid (elevation)" by airborne laser scanning

Table 3 Objects to be removed by Filtering (Planimetric features)

Object		Example
Traffic facility	Road facility etc	Road bridge (over 5m), Viaduct, Pedestrian bridge, Road information board etc., Illumination light, Signal light
	Railroad facility etc	Railroad bridge (over 5m), Viaduct (contains the viaduct of the monorail), Footbridge, Platform, Wire pillar, Signal post
	Mobile object	Car, Train, Ship
Building etc	Building and attached facility	House, Factory, Warehouse, Utility, Station, Greenhouse etc., Stand (Stadium), Gate, Pool, Wall
Small object		Monument, Torii, Cistern, Standpipe, Crane, Smokestack, Tower, Radio wave tower, Lighthouse, Transportation pipe, Power line
Water	Structure about water	Floating pier, Stone, Barrage, Water gate, Penetration water system
Vegetation		Tree, Bamboo wood, Hedge
Others	Others	Area under large-scale alteration construction, Yard storing building materials

Fig. 10 Work process flow