No. 1

TECHNICAL MANUAL

THE REMOTE SENSING ENGINEERING PROJECT PHASE II FOR THE DEVELOPMENT OF AGRICULTURAL INFRASTRUCTURE IN THE REPUBLIC OF INDONESIA

MARCH, 1991

JAPAN INTERNATIONAL COOPERATION AGENCY

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FOREWORD

In response to a request by the Government of the Republic of Indonesia to provide technical cooperation in the form of remote sensing technologies in order to establish a site selection system for agricultural development as part of the food production increase plan, the Government of Japan provided technical cooperation for 7 years, including the follow-up period, commencing in fiscal 1980 and the transfer of the basic remote sensing technology was duly completed. The Government of Indonesia then made a further request for additional cooperation for the further development and application of the basic technology and the Government of Japan commenced a 5 year protect in fiscal 1988.

In the field of remote sensing engineering while the technical aspects of satellite data, such as resolution, have significantly advanced, there is little literature available which compiles the application procedure of such data to agricultural development plans. Moreover, there are few expert with thorough knowledge of both remote sensing technologies and agricultural development plans. One of the few reference materials is "Technical Report on Site Selection System for Agricultural development" compiled during the Phase I period of the Remote Sensing Engineering Project which is still widely used by the counterparts in Indonesia.

On this background, the Japan International Cooperation Agency commissioned the Remote Sensing Technology Center of Japan to compile the basic technological development of remote sensing up to the present and the method to apply remote sensing data to agricultural development plans. It is hoped that this report will prove useful in the implementation process of Phase II of the Remote Sensing Engineering Project for the Development of Agricultural Infrastructure in the Republic of Indonesia.

Finally, I would like to express my utmost gratitude to those people and organizations without whose assistance and cooperation this report could not have been compiled.

March, 1991

Nobuyoshi Sakino
Director, Agricultural Development
Cooperation Department,
Japan International Cooperation Agency

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PART I

FUNDAMENTALS OF REMOTE SENSING

1.1 Outline of Satellite Data Use and Usable Data

Yukio Mukai

1.1.1 Characteristics of Satellite Data

Since the prospect of receiving observation data on the earth's surface from space was opened up in 1972 following the successful launch of Landsat-1, it has been becoming increasingly clear that satellite data are effective in terms of land use conditions and vegetation distribution surveys. Satellite data generally have the following conditions.

- Simultaneous Observation Capability of Wide Area
  As a satellite observes while flying at a high altitude in space at an excessively high speed, it can observe a very wide area within a short time with similar observation conditions.
- Repeatable Observation Capability
  As a satellite flies on the same orbit with a certain time cycle, it can repeatedly observe the same area which is extremely useful for purposes such as environmental monitoring.
- Highly Accurate Geometrical Characteristics
  The little changing altitude of a satellite during observation and the small angle of visibility result in few geometric distortions in an observation image which consequently resembles a geographical map.
- Electronic Sensor Observation
  The use of a multispectral scanner enables the acquisition of a multispectral two-dimensional digital image which in turn makes automatic classification and quantitative analysis by computer processing possible.

1.1.2 Satellite Data Analysis Technologies

The following satellite data analysis technologies are available using the characteristics of satellite data described in 1.1.1.

- visual interpretation using satellite photographs
- automatic classification based on multispectral classification
- change detection by registration of time sequential data.

(1) Visual Interpretation Using Satellite Photographs.

A multispectral two-dimensional image consists of data of multiple wavelength regions (called bands) and each band data form an image where small points called pixels are both vertically and horizontally arranged. A pixel represents the least discernible resolution by a sensor. The size of a pixel is determined by the instantaneous field of view of the sensor and the altitude of the satellite. Visual interpretation using a satellite photograph means that data of multispectral bands are allocated to red (R), green (G) and blue (B) to create a photograph to be visually interpreted by a person, This is the most basic technology to utilise satellite data. A photograph which is created by allocating data in the near infrared region to R, visible red wavelength to G and visible green wavelength to B is called a false color image where vegetation and urban areas are shown in red and blue respectively for easy recognition. This false color technique is often used for visual interpretation as it presents an easily recognisable picture. Two things are essential to obtain a good quality photograph for accurate interpretation, i.e. (i) suitable preprocessing and (ii) high performance image recorder.

Suitable preprocessing can be conducted using such techniques as geometric correction, contrast stretching, edge enhancement and HSI transformation. Geometric correction is a process which corrects remote sensing image to suit geographical maps and is a necessary preprocessing process to transfer interpretation results to a geographical map. Geometric correction is also required to register such mapping information as administrative boundaries on a remote sensing image and to register remote sensing images each other. In view of the importance of this techniques, it will be further discussed later.

Contrast stretching is a processing method to expand the variation range of the original input image data to utilize the full contrast range of the recording film and can be done by linear stretching, equi-histogram stretching or root stretching. Edge enhancement is a processing method to emphasize transitional areas of brightness level on an image and can be done by cubic convolution, differential or Lapracian processing. HSI transformation involves the transformation of data already allocated to R, G and B to such elements as hue (H), saturation (S) and intensity (I) which resemble the actual color information recognition method of the human eye with emphasis given to one of these elements. The resulting data are again transformed back to R, G and B data. This technique often provides an image which can be more easily interpreted than an image simply transformed with the R, G and B spaces. As there are many preprocessing techniques, it is important to select the appropriate technique to obtain information to be interpreted in the most effective manner.

A high performance image recorder is a device which adjusts the film exposure by changing the brightness of the R, G and B illuminants in accordance with the brightness levels of image data allocated to R, G, and B for each pixel. A stronger and finer exposure beam means higher resolution. The most popular high performance image recorder at present is a laser beam recorder using a laser as an illuminant.

- Geometric Correction Processing

Satellite data are usually passed on to users after geometric correction (called system correction) by a ground station to suit a geographical map. In general, data which have undergone system correction still have errors by a few pixels and the precise registration of system corrected satellite data for a geographical map with an error range of less than one pixel requires further geometric correction. Such a geometric correction procedure is shown in Fig. 1-1-1. Firstly, points which can be identified on both image and map (GCP: Ground Control Point) are determined to obtain an equation to show the relationship between the image coordinates and geographical coordinates. Using this equation, the image is transformed to register with the map. When the registration of two images is intended, the same procedure can be used except for the transformation of geographical coordinates to UTM coordinates.

(2) Automatic Classification Based on Multispectral Classification

(a) Interpretation of Substances by Different Spectral Reflectance Characteristics

Each substance has its own spectral reflectance characteristic which can in turn be used to interpret substances. This interpretation method is illustrated in Fig. 1-1-2. The spectral reflectance (radiation) characteristics of the most representative substances of nature, i.e. vegetation, soil and water, are shown in Fig.1-1-2 (a). To be more precise, a wavelength region of some 3μm or shorter shows a reflectance characteristics with sunlight being an illuminant while a longer wavelength region than 3μm shows a radiation characteristic which is dependent on the temperature of the substance in question. The observation wavelength of Bands 4, 5, 6 and 7 for Landsat MSS are shown with inverted triangular marks (∀). Assuming the two-dimensional space shown in Fig. 1-1-2 (b) where the reflectance intensities of Bands 5 and 7 form axes (called a feature space), the plotting of the reflectance intensities of vegetation, soil and water bands in this feature space results in Points A, B and C in Fig. 1-1-2 (b). For example, Point A is located at R7 on the vertical axis and R5 on the horizontal axis of the coordinates shown of Fig. 1-1-2 (b) as R5 and R7 indicate the reflectance intensities of vegetation to Band 5 and Band 7 respectively. The vectors from the origin to Points A, B and C are called feature vectors of vegetation, soil and water respectively. That each substance has its own peculiar spectral reflectance characteristic means that substances with similar characteristics are distributed to a single point or in the feature space. If the reflectance intensities of Bands

5 or 7 of a substance to be interpreted are known, these values are plotted in the feature space. The substance can then be interpreted in view of the plotted point. If such a point is Point N in Fig. 1-1-2 (b), the relative distance from Point N to Points A, B or C is the shortest between Point N and Point A, indicating that the substance in question has a similar characteristic to vegetation. If the observation data of n bands are used, substance interpretation can be conducted in the n-dimensional feature space.

(b) Automatic Classification Based on Multispectral Data

A multispectral scanner provides digital multiband data (called multispectral data) for each pixel and automatic classification of substances in the feature space is possible by means of computer processing using the principles described in (a) above. There are two ways of conducting such classification. One way is supervised classification where the points corresponding to Points A, B, C in Fig. 1-1-2 (b) are instructed as the training area. Another way is non-supervised classification where such instruction is unavailable.

The most popular classification method is supervised maximum likelihood classification, of which the classification procedure based on multispectral data is shown in Fig. 1-1-3. Firstly, such classification categories as vegetation, soil and water must be determined followed by the designation of training areas for these categories. Training areas can be designated by referring to various data such as aerial photographs, land use maps and field survey results (ground truth data) while displaying the input multispectral data on a display unit. Distribution in the feature space for each category is acquired using data within the training area designated for each category. The distribution acquisition method is closely related to the method of classification to be conducted later. For example, in the case of the maximum likelihood classification method which is the most popular classification method, distribution in each category is acquired in the form of the multidimensional normal distribution function which is determined by the average value and variance/covariance of data in the training area. Here, it is assumed that distribution in each category shows normal distribution in the feature space. The multi-dimensional normal distribution function for Category j is given by the following equation.

$$Pj(x) = \frac{1}{(2\pi)^{d/2} |\Sigma j|^{1/2}} \cdot \exp[-1/2 (x-\mu j)^t \Sigma_j^{-1} (x-\mu j)] \quad (1.1.1)$$

where, d: number of dimensions, i.e. observation bands

μj: mean vector of data in training area for Category j x: vector of observation value for unknown pixel

Σj: variance/covariance matrix of data in training area for Category j

The value of the multi-dimensional normal distribution function of each category (called probability density) for a pixel is calculated by substituting the observed value of the pixel in question in the input data for x. The pixel is classified into the category which gives the largest probability density. In general, a threshold is first established. If the maximum probability density is lower than the threshold, it is interpreted that the pixel does not belong to any category.

The most difficult process in the procedure described in Fig. 1-1-3 is the designation of a training area to represent a classification category, If possible, it is necessary to designate a homogenous training area which does not include other categories except the category which it represents, The collection of ground truth data is essential to designate a training area which correctly represents a category.

(3) Change Detection by Registration of Time Sequential Data

As satellite data have such characteristics as the capability of simultaneous observation over a wide area and the capability of repeatable observation, it provide data on the same area but taken at different times. It is very useful to detect changes by registering satellite data for many purposes and this change detection requires the following processing.

- precise registration of data observed at different times
- correction of brightness level of data observed at different times

For the precise registration of two images, each image must firstly be registered on a geographical map (geometric correction process). The degree of registration between the geometrically corrected images is then examined. If necessary, two stage processing where one image is registered to another image, considered as the reference image, is employed to obtain a precisely registered image which matches the geographical map.

The correction of the brightness level of data observed at different times is meant to correct differences in the brightness levels caused by different irradiation and/or attenuation by the atmosphere when the satellite data were observed. When the extraction of changes in image data is intended by substracting pixel by pixel from the registered images of two different times, the above described brightness correction must be conducted. For this brightness correction, statistics representing the brightness levels of the images should be calculated and a transformation equation to equalize the two sets of statistics should then be established. Using this equation, the brightness level of one image is transformed to be identical with the other image. Statistics representing the brightness level of an image are mean and standard deviation and accumulated histogram etc.. The best way to correct the brightness levels of two images is seemingly to equalize the accumulated histogram.

(4) Comparison Between Satellite Data and Ground Truth Data

Comparison between satellite data and ground truth data is necessary to obtain real ground surface information from satellite data. While satellite data are two-dimensional observation data on a wide area, ground truth data provide on-the-spot or limited area information in the satelite observation area. These ground truth data are obtained from aerial photographs, geographical maps and/or field survey results. If a field survey is conducted to obtain ground truth data, a photograph of the subject survey area should be prepared in advanced based on relevant satellite data where several survey points are also decided. The collection of ground truth data must be conducted while comparing these points with the photograph of the satellite data. Comparison of satellite data with ground truth data serves the following purposes in satellite data analysis.

- understanding of the relationship between the hue of the satellite image and actual ground surface conditions in the case of visual interpretation
- designation of training areas representing categories and understanding of the relationship between categories and actual ground surface conditions in the case of multispectral classification.
- understanding of the relationship between change characteristics of satellite data and changes in actual ground surface conditions in the case of change detection.

When ground truth data are compared with satellite data, the following time and spatial correspondence must be considered.

(a) Spatial Correspondence

Geometric correction of satellite data to suit the geographical map being prepared makes comparison between such data and the ground truth data obtained from a geographical map or other sources easy to achieve. If the subject of analysis is a land area, this comparison is relatively easy. Comparison of the satellite data with a sea area which has no island or coastal line nearby is difficult. In this case, however, the correspondence points can be determined by comparing the geometrically corrected satellite data with sea truth data, i.e. geographical data (latitude and longitude), of the data collection points.

(b) Time Correspondence

Time correspondence can be achieved by collecting ground truth data simultaneously with the observation of satellite data. The required severity of simultaneousness depends on the changing speed of the analysis subject. If the subject is a land area, changes on its surface are relatively slow, allowing observation to take place in the same season. In comparison, changes in a sea area are rapid, necessitating simultaneous sea truth data collection with the observation of satellite data.

1.1.3 Usable Data

Currently usable data are provided by such earth observation satellites as Landsat-4 and Landsat-5 (U.S.), SPOT-1 (France) and MOS-1 (Japan) and also by such meteorological satellites are NOAA-10 and NOAA-11. With the launch of SPOT-2 in January, 1990 and MOS-1b in February, 1990, observation data from these satellites should be available within the Phrase II period (1988 - 1993). The principal specificating such as wavelength of bands spatial resolutions and observation periods, of these satellites are shown in Table 1-1-1 - Table 1-1-3. While the NOAA-10 observes the thermal infrared band in only Band 4, NOAA-11 divides it into Band 4 and Band 5.

An appropriately located ground stations is able to directly receive observation data covering an area with a radius of about 2,400km (the station being the central point and the actual radius varies with the altitude of the satellite). The SPOTs have data recorders while the Landsats and MOS-1 do not. Fig. 1-1-4 - Fig. 1-1-6 show the distribution of ground stations in the world vis-a-vis the current Landsats, SPOTs and MOS-1.

With regard to Landsat data, the Landsat Indonesian station covers Sumatra, Borneo, Java and Sulawesi but not Irian Jaya. As of July, 1989, this station receives only Landsat MSS data. Since the Thai station covers most of Sumatra and Borneo, Landsat TM data on these areas can be obtained from the Thai station. The southern part of Irian Jaya is covered by the Australian station (Fig. 1-1-4).

As for SPOT data, the Thai station covers Sumatra, Borneo, Java and Sulawesi area. Irian Jaya also will be covered by the Australian station when in operation.

MOS-1 data on Sumatra, Borneo and western Java is supplied by the Thai station. The Australian station covers southern Sulawesi and Irian Jaya (Fig. 1-1-6).

1.1.4 Data on Case Study Areas

In Phase II of the present Project, the implementation case studies in the following areas is expected in order to solve problems associated with technical development.

- Riau Province (Indragiri River Basin, Central Sumatra)
- Samarinda Area (East Kalimantan)

The data available for these case study areas as of August, 1989 are given below.

(1) Landsat 4 and Landsat 5 Data
Path and Row Numbers

- Riau Province, which is fairly large, is covered on the following 6 scenes.

(Path)

(Row)	127	126	125
60			
61			

- The Samarina area is covered by 2 scenes, i.e. 116-60 and 116-61.

As the above 2 areas are included in the receivable area by the Thai station, the reception catalogue of Landsat MSS data of the Thai station for the period between 1983 and 1987 was studied. Dates with a cloud cover percentage of 10% or less are as follows.

Landsat Data

	Path-Row Numbers	Observation Date	Percentage of Cloud Cover (4 Zones, 10 Grades)
Riau Province	125-60	1983. 4. 14	1121
	127-60	1984. 10. 2	1101
	127-60	1985. 6.28	0000
	127-61	1983. 7. 1	1110
	127-61	1984. 10. 2	0000
	127-61	1985. 6. 28	1110
Samarinda	116-60	1983. 4. 15	0002
	116-61	1983. 4. 15	0001

The total number of observation scenes was 523, indicating that the probability of obtaining high quality data with a percentage of cloud cover of 10% or less is approximately 1% and that Indonesia is almost constantly covered by cloud. This may be explained by Indonesia's geographical features, i.e. between Indian Ocean and Pacific Ocean with several large islands.

Landsat TM Data

The study results on Landsat TM data on Riau Province received by the Thai station are shown in Table 1-1-4. The following 5 data appear usable for analysis of Riau Province.

Data	Path-Row Numbers	Observation Date
Landsat TM	125-60	1989.5.24
"	125-61	1989.6. 9
"	126-60	1989.6.16
"	126-61	1989.6.16
"	127-60	1989.4.20

(2) SPOT Data

K-J Nos. of SPOT Data

- Riau Province

(K)

(J)	275	274	273	272	271	270
350						
351						
352						

- Samarinda: 305-351; 304-351

In principle, SPOT data are provided on a chargeable programming request. A request was made for the purposes of the present study but was declined on the grounds that there were already too many requests for other Southeast Asian areas to deal with. With the recent launch of SPOT-2, however, it should be possible to make a programming request to obtain SPOT data in the future.

(3) MOS-1 MESSR Data

Path-Row Nos.

Raiu Province

	(Path)					
	4 0		3 9		3 8	
	W	E	W	E	W	E
(Row) 119						
120						
121						

- Samarinda: 29-121E; 29-121W

The MOS-1 MESSR is equipped with 2 sensors for path direction (east and west) and the observation data are named East and West. The Thai station started to receive MOS-1 data in July, 1988 and has the following data with a percentage of cloud cover of 10% or less.

	Path-Row Numbers	Observation Date	Cloud Cover (%)
Riau Province	38-119W	1988. 10. 5	10
	39-119W	1988. 5. 23	0

The total number of observation scenes is 147, indicating that the possibility of satellite data with a percentage of cloud cover of 10% or less is approximately 1.4% for MOS-1. The launch of MOS-1b in February, 1990, however, will improve the situation and data from this new satellite can be received by the Thai station. The MOS data received by the Thai station are processed by the NASDA-EOC, making the acquisition of such processed data by Japanese easier than some other satellite data. The active use of MOS data for the Project in the future should be seriously considered.

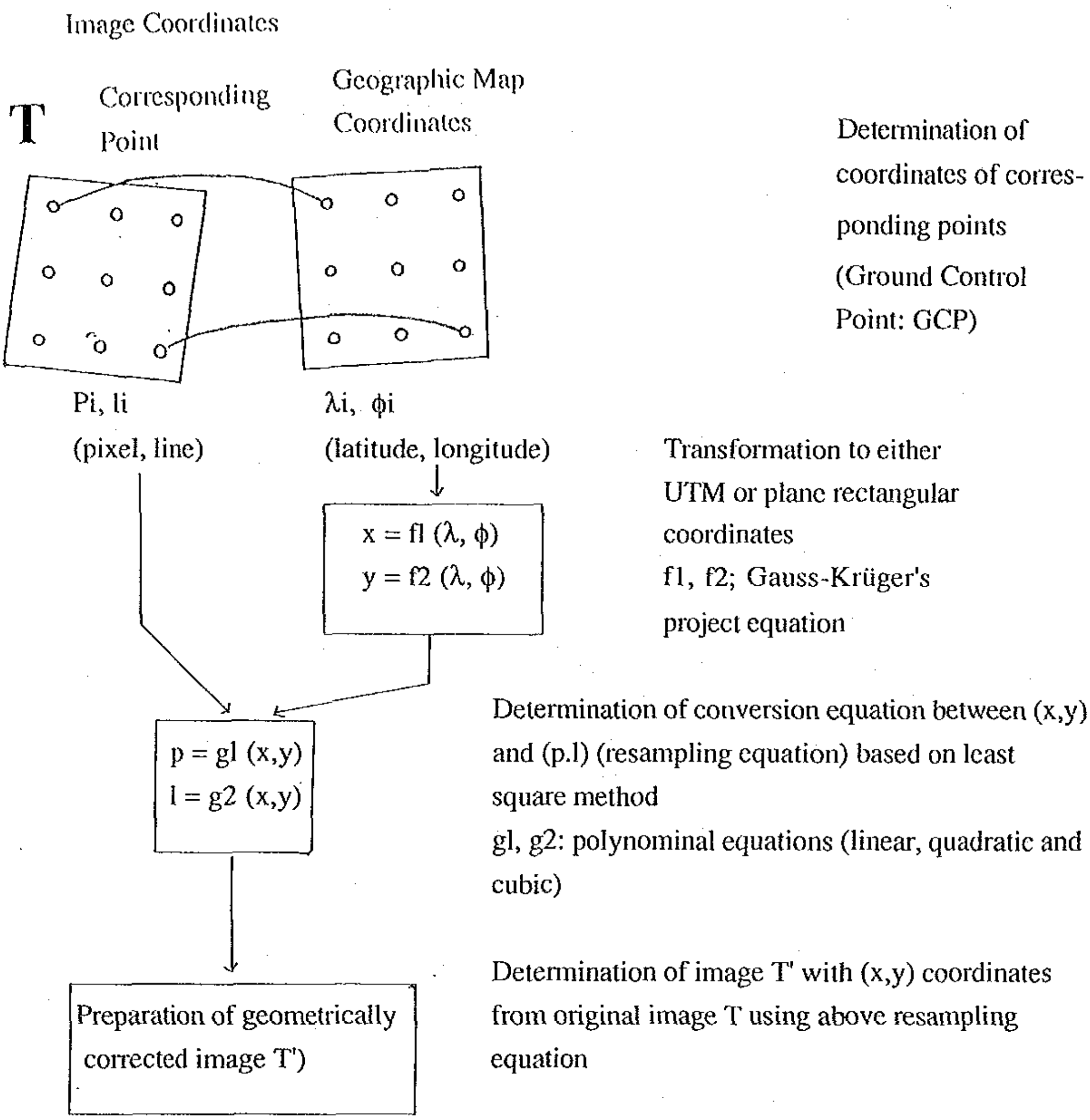
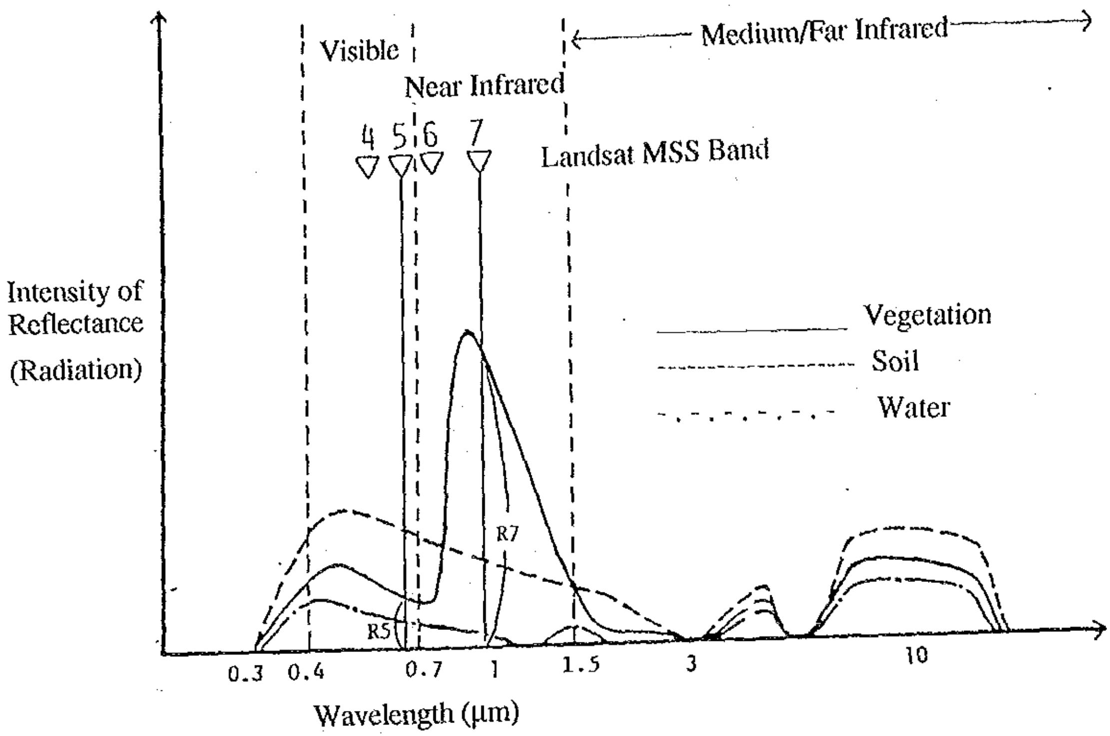


Fig. 1-1-1 Geometric Correction Procedure of remote Sensing Image

(a) Spectral Reflectance (Radiation) Characteristics of Substances



(b) Classification of Substance in Feature Space

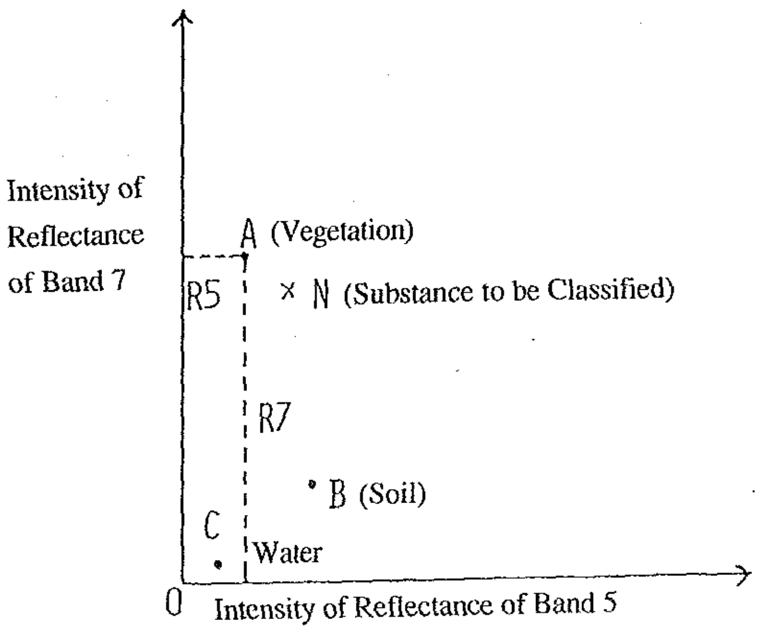


Fig. 1-1-2 Classification (Interpretation) of Substances Based on Spectral Reflectance Characteristics

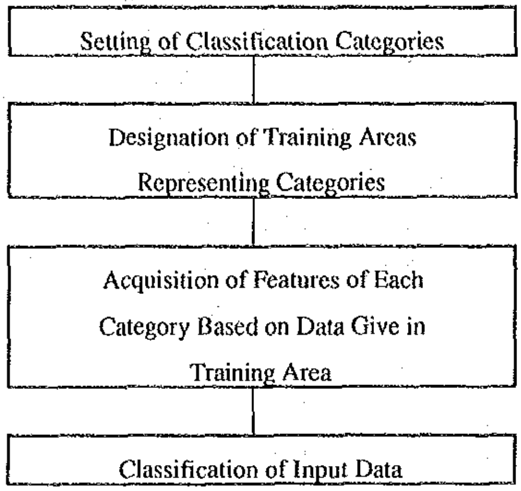


Fig. 1-1-3 Multispectral Classification Procedure

Table 1-1-1 Principal Specifications of Landsat Data

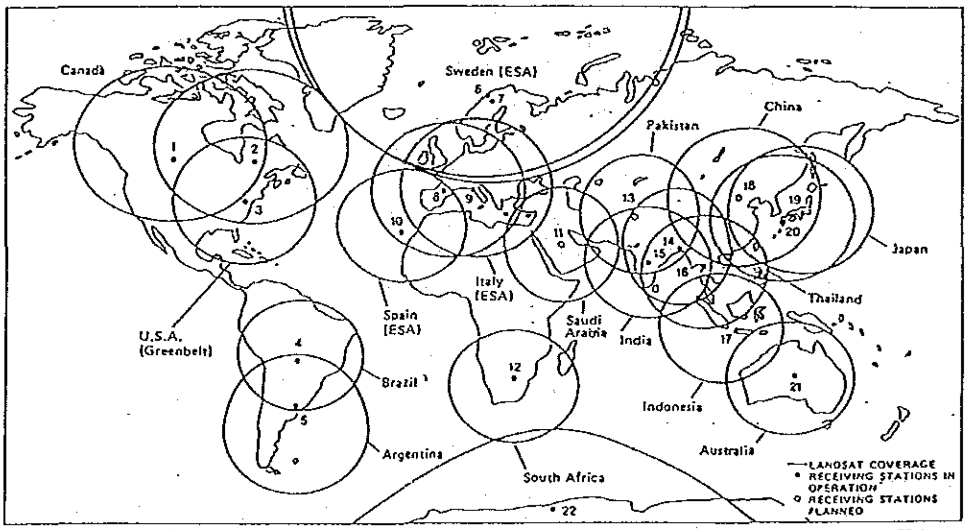
Sensor	Band	Wavelength (μm)	Spatial Resolution (m)	Remarks	Swath	Observation Interval
Landsat MSS	4	0.5~0.6	80	Green		
	5	0.6~0.7	80	Red		
	6	0.7~0.8	80	Near Infrared		
	7	0.8~1.1	80	"		
Landsat TM	1	0.45~0.52	30	Blue		
	2	0.52~0.60	30	Green		
	3	0.63~0.69	30	Red		
	4	0.76~0.90	30	Near Infrared	185 km	16 days
	5	1.55~1.75	30	Middle Infrared		
	6	10.40~12.50	120	Thermal Infrared		
	7	2.08~2.35	30	Middle Infrared		

Table 1-1-2 Principal Specifications of SPOT and MOS-1 Data

Satellite	Mode	Band	Wavelength (μm)	Spatial Resolution (m)	Remarks	Swath	Observation Interval
SPOT	Panchromatic		0.51~0.73	10	Green, Red	60 km	26 days
	Multi-Spectral	1	0.50~0.59	20	Green		
		2	0.61~0.68	20	Red		
		3	0.79~0.89	20	Near Infrared		
MOS-1	MESSR	1	0.51~0.59	50	Green	100 km	17 days
		2	0.61~0.69	50	Red		
		3	0.72~0.80	50	Near Infrared		
		4	0.80~1.10	50	"		
	VTIR	1	0.5~0.7	900	Green, Red	1,500 km	approx. 1 day
		2	6.0~7.0	2700	Red		
		3	10.5~11.5	2700	Thermal Infrared		
		4	11.5~12.5	2700	"		

Table 1-1-3 Principal Specifications of NOAA AVHRR Data

Satellite	Band	Wavelength (μm)	Spatial Resolution (m)	Remarks	Swath	Observation Interval
NOAA-10	1	0.58~0.68	1100	Visible	2,800km	approx. 1 day
	2	0.725~1.1	1100	Near Infrared		
	3	3.55~3.93	1100	Middle Infrared		
	4	10.5~3.93	1100	Thermal Infrared		
	5	Same as Band 4		"		
NOAA-11	1	0.58~0.68	1100	Visible	2,800 km	aprrox. 1 day
	2	0.725~1.1	1100	Near Infrared		
	3	3.55~3.93	1100	Middle Infrared		
	4	10.5~11.5	1100	Thermal Infrared		
	5	11.5~12.5	1100	"		



1. L・S Canada (Prince Albert) 2. S Canada (Gateneav) 3. L U.S.A. (Greenbelt) 4. L・S Brazil 5. L Argentina 6. M Norway (FSA)
7. L-S-M Sweden (ESA) 8. S France 9. L-M Italy (ESA) 10. L-M Spain (ESA) 11. L-(S) Saudi Arabia 12. L South Africa
13. L Pakistan 14. S Bangradesh 15. L-S India 16. L-M Thailand 17. L Indonesia 18. L-(S) China
19. L-M-(S) Japan (NASDA) 20. M Japan (Tokai Univ) 21. L-(S) Australia 22. M Japan (Shouwa-Base)

Fig. 1-1-4 Distribution of Landsat Ground Stations (December, 1986)

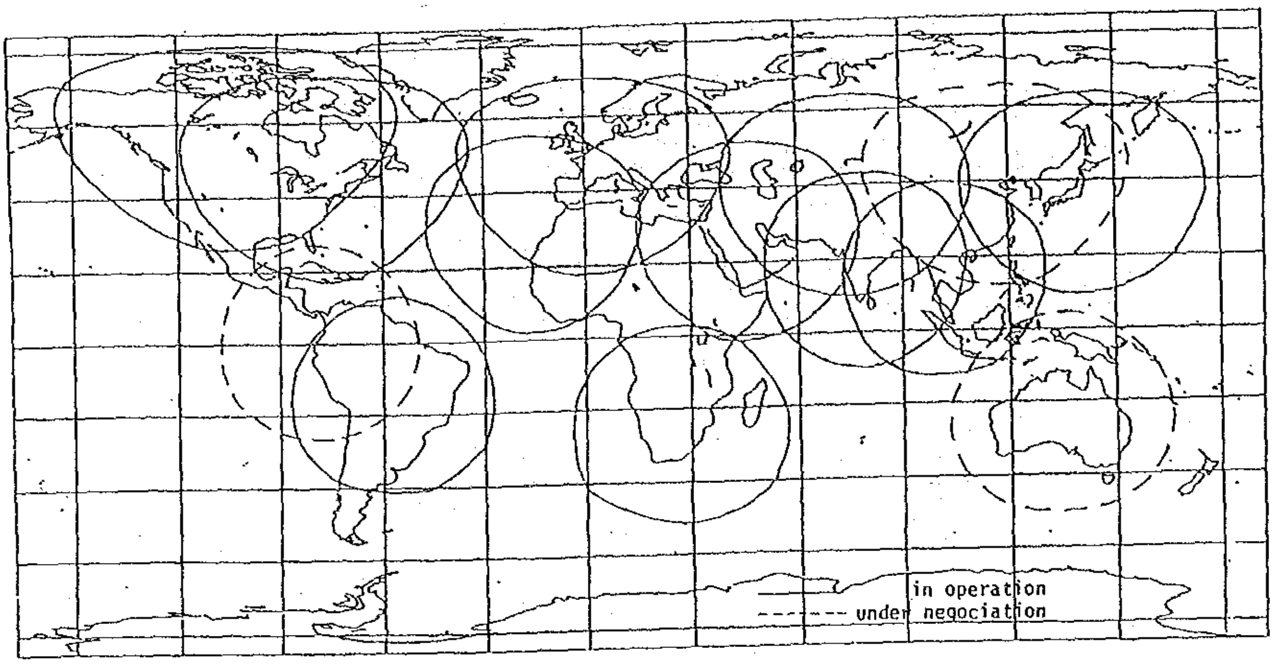


Fig. 1-1-5 Distribution of SPOT Ground Stations (January, 1989)

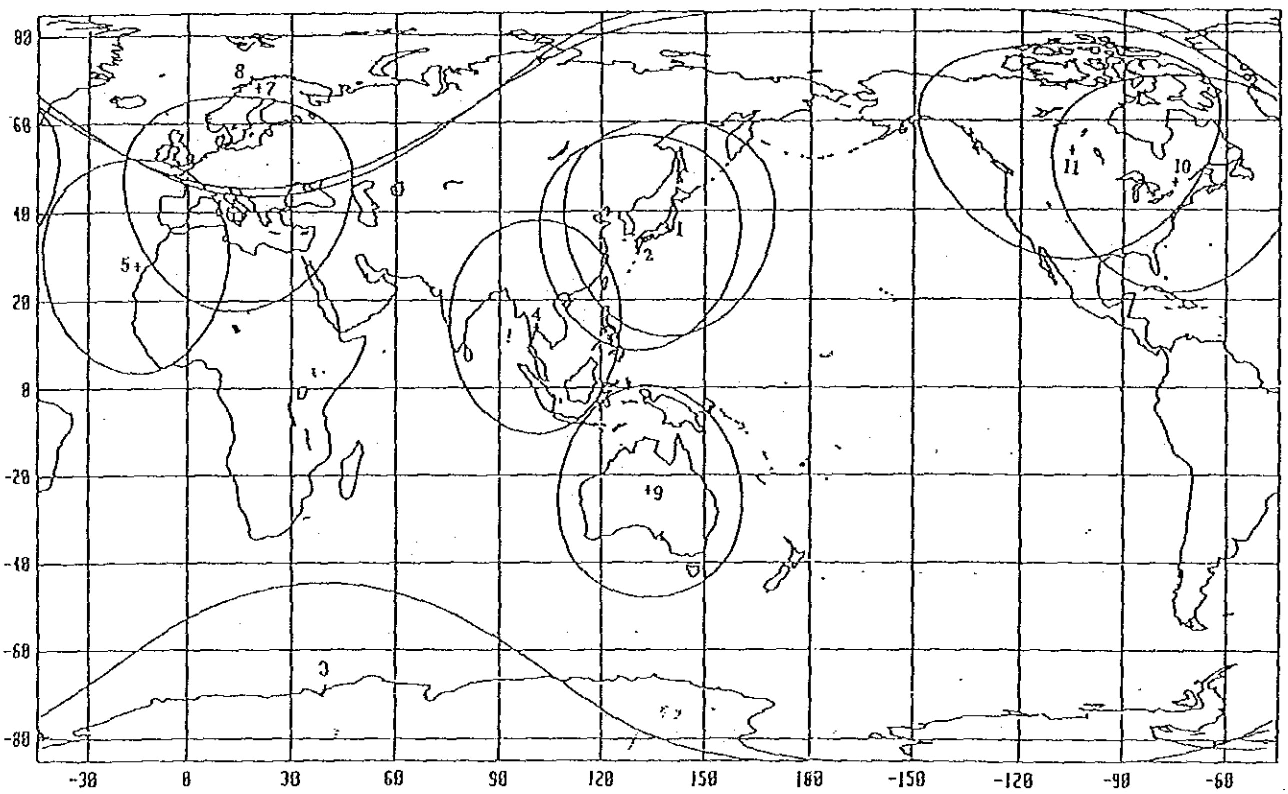


Fig. 1-1-6 Distribution of MOS-1 Ground Stations (October, 1989)

LANDSAT-5 CATALOG PRINT BY SELECT RANGE PATH, ROW, AND DATE
ORDER BY PATH, ROW, AND DATE

23-Jun-1989 Page 1

PATH	ROW	ACQUISITION DATE	PASS IDENTIFICATION	SENSOR	NASA IDENTIFICATION	SCENE LATITUDE	SCENE LONGITUDE	Q 1	Q 2	Q 3	Q 4	QUALITY
125	060	29/Dec./1987	125	TM	51398-024549	S00.00	E103.86	6	7	6	5	0
125	060	15/Feb./1988	125	TM	51446-024641	N00.00	E103.81	8	4	4	6	0
125	060	18/Mar./1988	125	TM	51478-024659	S00.00	E103.82	8	8	7	8	0
125	060	18/Mar./1988	125	TM				7	5	8	8	0
125	060	9/Aug./1988	125	TM	51622-024744	N00.00	E103.81	5	4	8	3	0
125	060	10/Sep./1988	125	TM	51654-024749	N00.00	E103.80	5	8	8	8	0
125	060	31/Dec./1988	125	TM				3	1	3	2	0
125	060	22/Apr./1989	125	TM				5	5	1	3	0
125	060	8/May/1989	125	TM				5	5	7	7	0
125	060	24/May/1989	125	TM				1	1	2	2	0
125	060	9/Jun./1989	125	TM				8	2	4	2	0
125	061	15Feb./1988	125	TM	51446-024705	S01.45	E103.50	6	8	8	8	0
125	061	31/Dec./1988	125	TM				5	5	7	7	0
125	061	22/Apr./1989	125	TM				1	3	1	6	0
125	061	8/May/1989	125	TM				7	7	4	7	0
126	061	9/Jun./1989	125	TM				0	1	0	0	0
126	060	6/Feb./1988	126	TM	51437-025245	S00.00	E102.26	3	6	5	7	0
126	060	10/Apr./1988	126	TM	51501-025311	S00.01	E102.31	8	6	7	8	0
126	060	26/Apr./1988	126	TM	51517-025321	S00.01	E102.30	5	6	5	7	0
126	060	28/May/1988	126	TM	51549-025341	N00.00	E102.26	8	2	7	2	0
126	060	15/Jul./1988	126	TM	51597-025355	N00.00	E102.25	7	8	7	7	0
126	060	31/Jul./1988	126	TM	51613-025357	N00.00	E102.25	7	8	6	0	0
126	060	23/Jan./1989	126	TM				7	7	8	8	0
126	060	31/May/1989	126	TM				7	4	8	6	0
126	061	6/Feb./1988	126	TM	51437-025309	S01.45	E101.96	3	6	6	8	0
126	061	9/Mar./1988	126	TM	51469-025329	S01.45	E101.96	8	8	8	8	0
126	061	26Apr./1988	126	TM	51517-025344	S01.45	E101.99	3	5	7	6	0
126	061	28/May/1988	126	TM	51549-025405	S01.45	E101.95	6	6	6	7	0
126	061	13/Jun/1988	126	TM	51565-025410	S01.45	E101.94	2	5	1	2	0
126	061	3/Oct./1988	126	TM	51677-025416	S01.45	E101.98	5	6	1	6	0
126	061	28/Mar./1989	126	TM				7	6	4	7	0

Table 1-1-4 Study Results of Landsat TM Data on Riau Province (1/2)

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PATH	ROW	ACQUISITION DATE	PASS IDENTIFICATION	SENSOR	NASA IDENTIFICATION	SCENE LATITUDE	SCENE LONGITUDE	Q 1	Q 2	Q 3	Q 4	QUALITY
127	060	27/Dec./1987	127	TM	51396-025808	S00.01	E100.77	7	8	4	5	0
127	060	13/Feb./1988	127	TM	51444-025859	S00.00	E100.73	7	8	2	7	0
127	060	16/Mar./1988	127	TM	51476-025920	S00.00	E100.73	8	8	2	5	0
127	060	1/Apr./1988	127	TM	51492-025926	S00.00	E100.73	2	0	4	3	0
127	060	17/Apr./1988	127	TM	51508-025927	S00.01	E100.76	6	6	5	2	0
127	060	4/Jun./1988	127	TM	51556-025954	S00.00	E100.71	4	4	5	6	0
127	060	7/Aug./1988	127	TM	51620-030007	N00.00	E100.72	1	1	0	2	0
127	060	24/Sep./1988	127	TM	51668-030005	S00.00	E100.73	3	1	3	5	0
127	060	27Nov./1988	127	TM				3	2	6	6	0
127	060	20/Apr./1989	127	TM				1	2	6	1	0

Table 1-1-4 Study Results of Landsat TM Data on Riau Province (2/2)

1.2 Multi-Stage Survey Method

Yasufumi Emori

Introduction

The analysis of satellite images in the early stage of remote sensing was assisted by the prior determination of such spectral characteristics of ground objects as vegetation and soil and of spatial characteristics in a laboratory or actual environment, measurement of the same objects from a higher altitude using an airplane and the study results of changes of these characteristics due to atmospheric conditions or growth conditions, i.e. sparce or dense vegetation. At present, however, separate interpretation of satellite images with varying scales and aerial photographs and the subsequent comparison of the interpretation results are effective to acquire geological data and this procedure is widely used in the geological field, especially for geological surveys on mining and oil resources.

The data acquisition method involving scanning the ground from various altitudes is called a multi-stage method. The use of this method to survey an area where a geological survey has already been completed for the purpose of applying the survey results to an undeveloped area is considered extremely important in the field of geology as a means to provide new additions to the ground data of an undeveloped area. It is now known that the interpretation results of a small-scale composite image are sometimes more valuable than the detailed interpretation results of a large-scale image taken from a low altitude.

The application of the multi-stage method to agriculture has already been proposed in Phase I to select suitable farmland in Indonesia. Here, the proposed processes were the selection of several suitable farmland sites in a wide area using Landsat images, aerial photography of the selected sites, examination of the compatibility of satellite data with aerial photography data using meduim-scale images or enlarged satellite images and finally, the use of large scale aerial photographs at the actual implementation stage. The necessary experiment involving satellite images with a scale of 1:1,000,000 was completed in Phase I. The relationship between the photo scale and resolution in remote sensing is described below.

1.2.1 Scale and Resolution of Multi-Stage Images

Conventional aerial photograph interpretation use ordinary photo films and has a history of more than 50 years in commercial and military applications. The precision of an aerial image is called resolution which indicates the number of black and white lines per millimeter. In the case of 30 lines/mm, 30 lines are distinguishable per millimeter. In other words, a line with a width of 0.033mm can be distinguished. As optical resolution considers white and blank lines as a pair, the optical pixel width is almost identical to the width of the latest coupled device (CCD) pixel of approximately 0.016mm.

In general, the resolution of an aerial photograph is related to the resolution of the lens, resolution of the photo film, the Haze factor determined by the degree of light scattering caused by moleculars in the atmosphere, the reflectance rate and contrast of the photography subject solar illuminance. The resolution of an ordinary aerial photograph is 30 lines/mm.

Resolution of 60 lines/mm can be obtained in clear weather with a low Haze factor. The use of small grain photography material and a camera equipped with a forward motion compensator (FMC) mechanism allows resolution of 200 lines/mm which is equivalent to a pixel width of 0.008 - 0.0025mm and beyond the present capability of a CCD. For interpretation of whether or not an object exists on a photograph, the existence of 2 or 4 pixels at represent such an object is said to be sufficient. For the detection of an object, therefore, resolution of a least 1 - 2 lines/mm is necessary. To determine whether or not a detected object is an automobile resolution of 4 - 7 lines/mm is required. In other words, an object must have 8 - 14 pixels. To obtain further information, such as the manufacturer and model type of an identified automobile, resolution of 7 - 14 lines/mm or 14 - 28 pixels is believed necessary based on past experience.

Interpretation of a ground object on an image requires that the object must be a certain size. The size of an image on a photograph is determined by the focal distance of the camera and the altitude. Given a constant focal distance, the altitude must be changed to obtain an image of a certain size. The photo scale in defined as follows.

$$\text{Photo Scale} = \frac{\text{Focal Distance}}{\text{Altitude}} = \frac{\text{Distance on Photograph}}{\text{Distance on Ground}}$$

Consequently, the photo scale is an essential component of an image for interpretation purposes. Assuming the resolution of a camera and the size of a farmer working in a field are 30 lines/mm and 0.3m x 0.7m respectively, the minimum size of an image in which the farmer can be interpreted as such is 4 lines/mm, i.e. 0.132mm. The required photo scale is approximately 1:2,000 in view of the following calculation result.

Photo Scale = 0.3mm ÷ 0.132mm = 2,272

Table 1-2-1 gives the scales required for photo interpretation in the agricultural field. These scale values are empirically obtained and can be used as practical guidelines.

1.2.2 Scales of Multi-Stage Images

The normal scales used for multi-stage remote sensing are 1/1,000,000 - 1/250,000 for Landsat images, 1/130,000 - 1/12,600 for ultra-high aerial photography by a U2 aircraft, 1/80,000 - 1/58,000 for high altitude aerial photography and 1/58,000 - 1/20,000 for meduim-low altitude aerial photography. Figs. 1-2-1 - 1-2-3 show multi-stage remote sensing images used for geological structure surveys to probe for oil resources.

Fig. 1-2-1 is a Landsat image (scale: 1/1,000,000) of Wyoming State in the U.S. showing the rough geological structure which enables the drawing of the lineaments given in Fig. 1-2-1-b. Fig. 1-2-2 is a high altitude image (scale: 1/56,000) of Area C in Fig. 1-2-1-b showing a well developed river system, in a basin. Fig. 1-2-2-b shows lineaments and faults identified from Fig. 1-2-2 and these lineaments and faults are more detailed that those in Fig. 1-2-1-b. Fig. 1-2-3 is a medium altitude image (scale: 1/36,000) of the same area (Area C), enabling more detailed classification of the topographical features. The original Landsat image can be analyzed in detail using such large-scale images.

While the above method is frequently used for mineral resources probing, it can also be used for agricultural development purposes. As such, the use of the multi-stage remote sensing method was proposed by the Department of Public Works for the Phase I project. The relationship between an image and the mapping scale in the agricultural field is further discussed below.

a) Scales for Soil Type Interpretation

It is unnecessary to say that the selection of the correct soil type is extremely important for agricultural development. A primary development effort to convert undeveloped farmland to farmland requires land use classification and soil and vegetation surveys. While the land inclination can be calculated to a certain degree using stereo images, SPOT is the only satellite providing such images at present. Soil types, i.e. gravel, sandy silt, loamy clay and organic soil (peat and black coal), etc., can usually be interpreted based on the color tones of images (spectral reflectance characteristics), grain properties or vegetation types. When the ground is covered by vegetation, the soil type is guessed by the vegetation type and conditions. It is now possible to interprete soil types by special processing techniques even if the ground is covered to some extent by vegetation. As the identification of sand or gravel requires the surface grain size, a large-scale image of at least 1/5,000 is required to determine the grain size.

The application of an algorithm developed in Japan must be carefully executed vis-a-vis Indonesian land of which the vegetation types and conditions are unknown. A soil type estimate using vegetation requires data on the crown shape and size,necessitating the use of a scale in the range of 1/8,000 - 1/7,000.

The topography of an alluvial plain is closely connected to its soil. For example, stratified land, natural land, natural levees and valley plains tend to have a high sand or silt content while back swamps tend to have clayey silt or black coal.

Deltas tend to have clay and fine sand while waste-filled valleys tend to have high proportions of peat and black coal. Consequently a study on the topographical details gives a rough idea of the soils involved. A scale of 1/25,000 - 1/20,000 is sufficient to obtain topographical details of a medium size area but a scale of 1/13,000 - 1/10,000 is frequently used for a small area.

b) Scales for Forest Interpretation

A forest inventory survey is usually conducted on such items as species, tree height, forest density, crown density and fallen tree ratio, etc. and the species largely differ between tropical and temperate zones. Trees in a temperate zone are classified into needle-leaf and broad-leaf trees and also into evergreens and deciduous trees, Needle-leaf trees usually appear darker than broad-leaf trees and the crown often has a cone shape. They also appear smaller than broad-leaf trees of the same height. Broad-leaf trees appear light grey in color with an irregular but circular crown. The existence of broad-leaf trees can be interpreted based on the spectral characteristics on a satellite image with a scale of 1/1,000,000. However, the tree height and other items cannot be calculated.

In principle, the classification of forest type is based on the every tree count results and a forest with more than 70% needle-leaf trees is called a neddle-leaf forest. The same proportion applies in the case of a forest described as a broad-leaf forest.

The tree height is determined by stereoscopic observation. A tall tree has a height of 6m or more, a medium tree has a height of 1 - 6m and a low tree has a height of less than 2m.

The forest density is determined by the number of the same species with the same tree height in a unit area (100m x 100m).

$$\text{Density} = \frac{\text{Unit Area } (10{,}000m^2)}{\text{Number of Trees}}$$

The forest classification based on the forest density and d.b.h. is given below.

DBH/Density	< 10cm	10 - 15cm	>15cm
< $9m^2$	medium density forest	dense forest	dense forest
9 - $20m^2$	thin forest	medium density forest	medium density forest
> $20m^2$	thin forest	thin forest	medium density forest

The crown density means the relative proportion of the crown area vis-a-vis the unit land area and is calculated using the following equation.

$$\text{Crown Coverage} = \frac{\text{Crown Area}}{\text{Unit Land Area}} \times 100$$

In general, 4 categories are used to represent coverages of 0 - 10%, 10 - 40%, 40 - 70% and 70 - 100% and the classification is normally based on the crown density chart (Fig. 1-2-4).

The fallen tree ratio is calculated from the number of fallen trees in the unit area.

A scale allowing crown interpretation is required for the implementation of such a forest inventory survey, indicating a minimum scale of 1/8,000 - 1/7,000. The species in an orchard are interpreted in terms of tree parameters, branch spread, fencing, tree pattern and planting pattern, etc.

Farmland is usually either paddy fields or dry farming land but the characteristics largely vary depending on the season. The interpretation of farmland is usually made in terms of the spectral characteristics, existence of footpaths, irrigation network and crop patterns, etc. A scale of 1/50,000 should be sufficient to distinguish between a paddy field and dry farmland. In the case of an orchard or wasteland, a scale of 1/8,000 - 1/7,000 may be necessary. Furthermore, a scale of 1/5,000 is required to determine the possible crop yield and sandy or gravel wasteland.

c) Scales for Water System Interpretation

Water systems and rivers are prerequisites to secure irrigation water for agricultural development. In the case of a medium size area, knowledge of these systems and rivers is particularly important for irrigation, drainage and disaster prevention plans. The water use conditions can be divided into such lineal components as water channels and local vegetation management and such two-dimensional components as irrigation/drainage networks, areas with insufficient irrigation water and areas with insufficient drainage, etc. In addition, concrete decisions are necessary for a development design pertaining to the locations and sizes of both large and small floodgates and other design layouts.

A water system is described in terms of the valley density (VD) and the segment frequency (SF), i.e. valley length in the mountain range. The actual values of VD and SF depend on the photo scale and photographs with a scale of 1/50,000 are usually used.

A scale of 1/8,000 - 1/7,000 is used for the interpretation of large floodgates or large irrigation channels while a scale of 1/5,000 is frequently used for the interpretation of small floodgates and irrigation pumping stations, etc.

A scale of 1/5,000 is used for the design of irrigation/drainage channels. Major bed sandbars on river banks and shoals can be interpreted with this scale.

A scale of 1/13,000 - 1/10,000 is mainly used for the interpretation of river embankments, revetments and large floodgates.

d) Scales for Artificial Structure Interpretation

An agricultural development project can involve sub-projects relating to irrigation, drainage, farmland improvement, farming road improvement and disaster prevention for farmland, etc. An irrigation and drainage project may involve the construction of dams, irrigation channels, intake facilities (pumping stations), diversion works and drainage channels, etc. Several pumps may be used at an irrigation and drainage facility.

Roads are important infrastructure for the transportation of development equipment and materials, fertilizer, agricultural products and others. A paved road is generally interpreted from its surrounding areas due to its constant width. Concrete paving is particularly clear because of high reflectance. In contrast, a gravel road or an earth road tends to have an irregular width and the kerb is not as clear as that of an asphalt or concrete paved road.

A scale of 1/25,000 - 1/20,000 is appropriate for the interpretation of bends of a 2 - 4 lane road while a scale of 1/13,000 - 1/10,000 is required to interprete road widths, level crossings and damaged sections. A more detailed scale of 1/8,000 - 1/7,000 is used to interprete the road surface type and the existence of roadside trees, etc. A scale of 1/5,000 is required to interprete road shoulders, roadside lamps and other auxiliary facilities.

The total length, vehicle road width, type, span structure and piers must be interpreted in the case of a large bridge over a river. It is generally agreed than a scale of 1/30,000 - 1/20,000 is required for the intepretation of the total bridge length and vehicle road width. Similarly, a scale of 1/13,000 - 1/10,000 is required for the interpretation of a small bridge, 1/8,000 - 1/7,000 for the bridge type (arch, truss, etc.), river bed, revetment and bridge pier and 1/5,000 for the effective bridge height and caltilever girders.

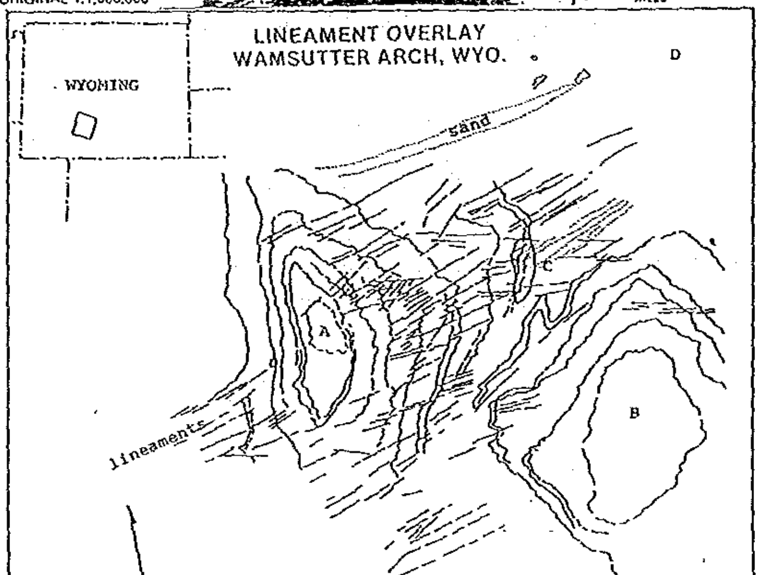
Table 1-2-2 gives a list of the required scales to inteprete topographical features, water systems, vegetation and artificial structures in accordance with past experience. The approriate scale must be selected for actual application taking the actual conditions into consideration.

e) Scale for Digital Images

The scales which have so far been discussed are empirical scales required for the visual interpretation of analogue photographs. A digital image differs from a photo film in that it allows both free enlargement and contraction of the scale using the minimum pixels. However, it should be noted that the minimum number of pixels is still required to detect and interprete an object. In the case of SPOT, anything smaller than 30m in length (width) cannot be interpreted on the ground because of SPOT 1s resolution limit.

Since the measurements of the detector and optical focal distance of the scanner on board a satellite are constant, either the satellite altitude must be reduced or the focal distace of the lens must be extended to acquire a suitable scale for interpretation, Digital analysis is said to be more accurate and effective than analogue analysis (visual interpretation) but computer analysis is not yet as seen in the case of texture analysis. Moreover, as an algorithm for digital analysis roughly follows the established algorithm for analogue interpretation, it is incorrect to say that digital analysis is more important than analogue analysis. In short, hybrid analysis using both the digital and analogue methods will be used for the forseeable future and the scales used for visual interpretation described above should be valid for digital analysis.

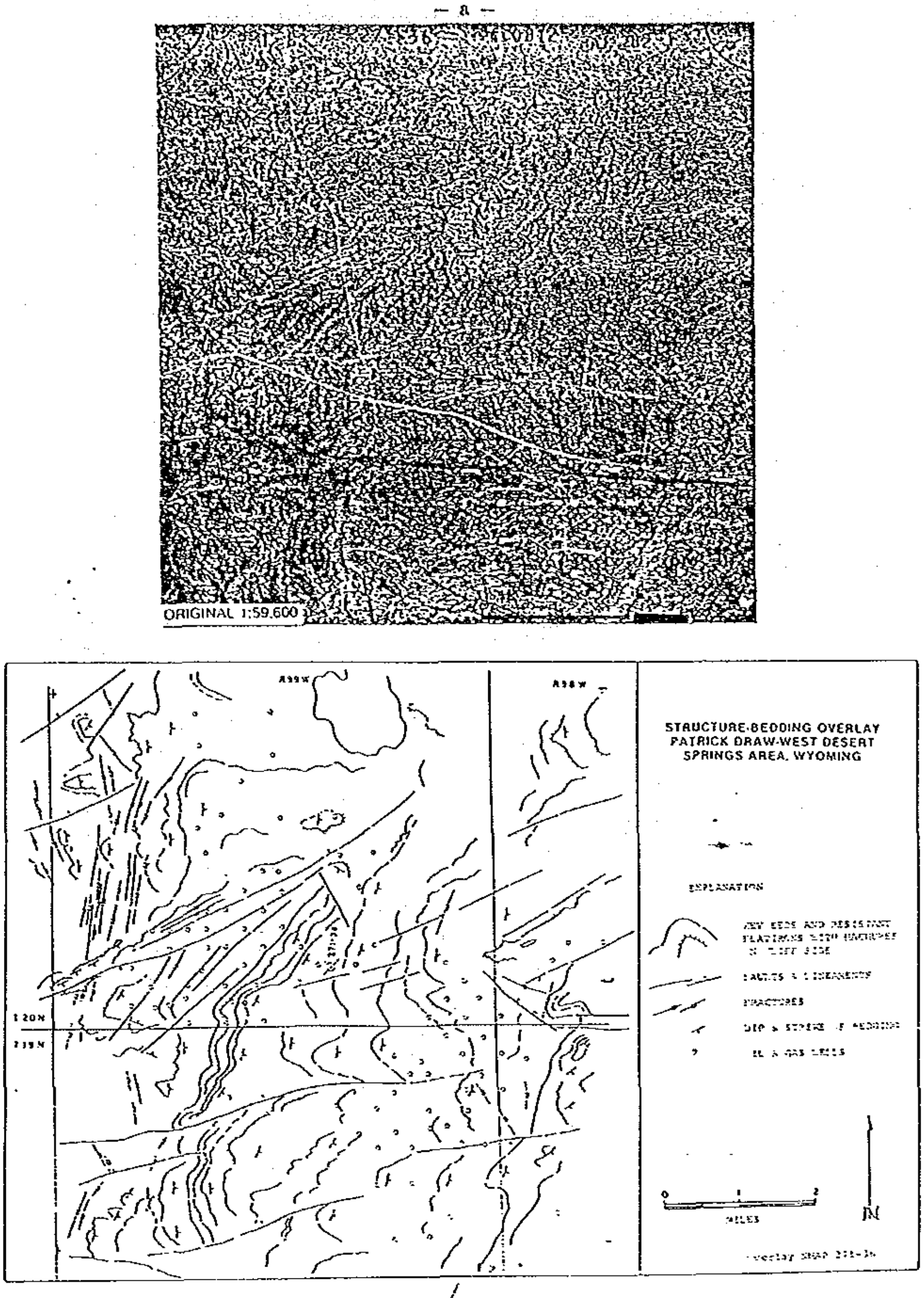
— a —



— b —

Fig. 1-2-1 Landsat scene 1409-17294 and lineament overlay, southwest Wyoming.

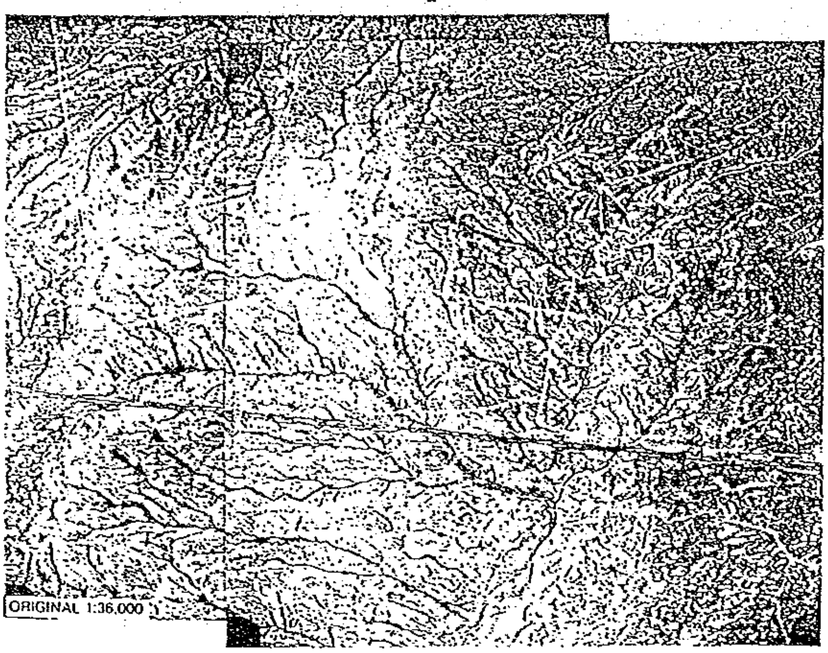
— a —

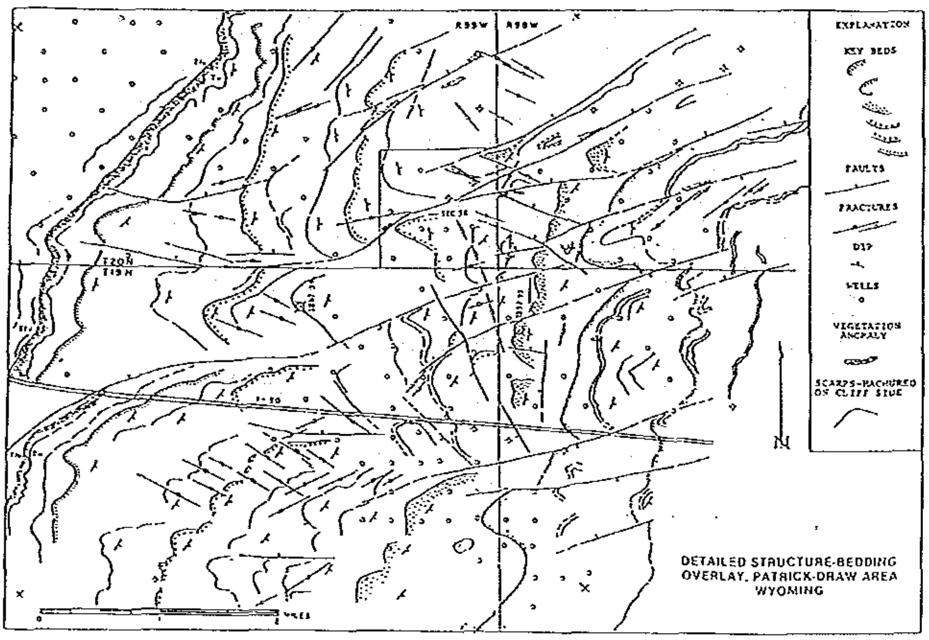


— b —

Fig. 1-2-2 High altitude photo and structural overlay, Patrick Draw area, Wyoming.

— a —

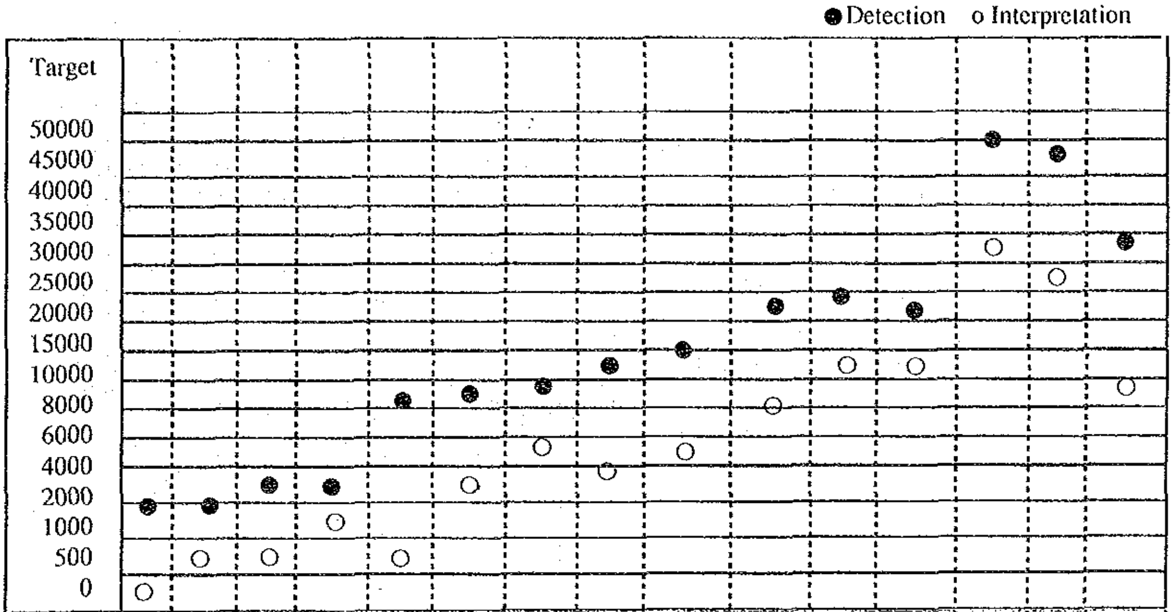




— b —

Fig. 1-2-3 Low Altitude photo and structural overlay, Patrick Draw area, Wyoming

Table 1-2-1 Required Photo Scales for Visual Interpretation



Target	plough/hoe	farmer	double fence	double fence	railway track	compost heap	group of compost heaps	jeep	small truck	large truck	small farmhouse	farm warehouse	small jet	small propeller plane	small boat
Condition (s)	on the ground	working	old	new	single track	single heap	group of heaps	stationary in open area	stationary in open area	stationary in open area	detached	detached	single airplane	single airplane	crossing a river
Rough Size (m)	1 x 0.06	0.7 x 0.3 (m)	3 x 30	3 x 30	1.2 x 1	1.2 x 1	1.2 x 1	3.3 x 1.5	4.8 x 2	6.4 x 2.2	7 x 5	2 x 15	17 x 7	10 x 7	10 x 2

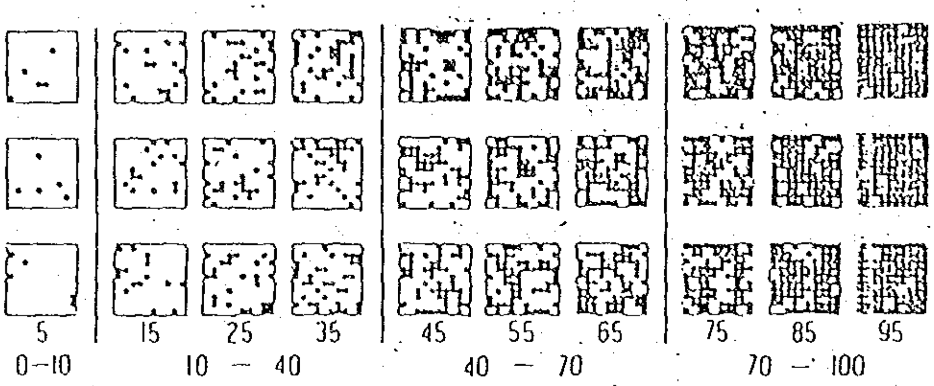


Fig. 1-2-4 Crown Density Chart

	Artificial Structures					Others	
	Roads	Bridges	Tunnels	Ports	Railways	Disaster Areas	Cities
1: 25,000 1: 20,000	alignment; toll gates; lay-bys; 2-level crossing; elevated sections	total length; vehicle road width	location	piers; jetties; landing space; docks; wharves; breakwaters	station buildings; station squares; elevated railway bridges	disaster areas	urban landscape
1: 13,000 - 1: 10,000	road width; level crossings; damaged sections; unclear roads	total length of small bridge; bypasses; vehicle road width		floating jetties; sheds; railway tracks	platforms; double track bridges; cargo yards; water tanks; cars	degree of disaster; estimated damage; access routes	district classification; measurements; squares; road measurements
1: 8,000 - 1: 7,000	surface conditions; effective height; road side trees; center zones	bridge type (arch or truss); abutments; bridge piers	entrance and exit	pier height; large cranes	station (yard) layout; effective length; auxiliary facilities		building details; monitor points; heliports; helicopters
1: 5,000	road details such as shoulders and street lamps	girder type; effective height		loading equipment; mooring posts	loading equipment; water tanks; command posts; overhead wires	detailed damage estimate	helicopter model
Remarks	In general, a photo with a scale of 1/10,000 is used for interpretation.	Infrastructure can not be interpreted. A scale of 1/20,000 allows rough interpretation while a scale of 1/10,000 allows detailed interpretation.	Construction materials are difficult to interprete.	Oil supply and loading/ unloading movements are difficult to interprete. Scales of 1/60,000 and 1/10,000 allow rough and detailed interpretation respectively.	Signals and signs can not be interpreted.	Scales of 1/20,000 and 1/10,000 allow rough and detailed interpretation respectively.	

Table 1-2-2 (1/2)　　Required Scales for Interpretation

	Topography	Rivers	Coats	Forest	Vegetation
1: 25,000 - 1: 20,000	(Large Categories) high mountain ranges; lowland; high hills; low hills (Small Categories) terraces; fault bumps; river terraces, terrace surfaces; lakes; swamps; ponds; reservoirs	(Running Water) location; river width; stage; flow direction; river reservation conditions; dams; waterfalls	shore line; inclination		paddy fields or dry fields (before harvest)
1: 13,000 - 1: 10,000	(Large Categories) rolling land; platforms (Small Categories) hillside works; ridges; swamps; back sloughs (Inclination Categories) 0°-10°, 10°-20°, 20°-30°	(Bank Conditions) embarkments; revetments; small channels: weirs; floodgates; small waterfalls; irrigation channels	small topographical features; ground objects; swells; fixed shore nets; wreaked boats; reefs; large waves	broad or needle-leaf forest; density of needle-leaf forest; plant cover ratio	paddy fields or dry fields
1: 8,000 - 1: 7,000	1-3m cliff line	bank conditions; bank height	cross-section vegetation; small ground objects; shoals; waves; turbulent flow	crown shape; tree height; density of broad-leaf forest species	orchards; wasteland; mulberry fields
1: 5,000		major beds. sand bars; shoals; small floodgates; ground water pipes; small irrigation channels			plant height; gravel or sandy land
Remarks	A scale of 1/20,000 allows classification of topographical features. A scale of 1/10,000 is required for quantitative interpretation and presentation	Water depth and riverbed soil type cannot be identified	Clear length and forest floor can be interpreted. A scale of 1/10,000 - 1/8,000 should be used for detailed interpretation of tree diameter.		Soil type and crop type are difficult to interpret.

Table 1-2-2 (2/2)

1.3 Integration of Multiple Data (Such as GIS) and Their Utilization

Hideki Shimamura

Introduction

The integration of geographic information system (GIS) technology and remote sensing technology has increasingly become of paramount importance in recent years. From the viewpoint of a GIS, remotely sensed data such as Landsat data are very important information sources as they are relatively up-to-date and are easy to input into a computer system. They can also be utilized in a time series manner. The integration of remote sensing data in a GIS helps to create small-scale GIS maps and to solve the problem of data input to a computer. Conversely, from the viewpoint of remote sensing, a GIS provides excellent technology to manipulate and analyse data in bulk volume. A GIS has stored base maps of municipalities and socioeconomic data, such as national census data, which are absent from remote sensing data. The effective and expansive integration of these two technologies has more potential to create new application fields than in the case of them undergoing separate development processes.

Despite recognition of the promising potential, integration has proved more difficult than once anticipated. One reason for the difficulty is that integration requires a much larger computer system than before. However, the crucial problem arises from the fact that the data models of these two technologies are quite different from one another. This paper addresses the GIS which is becoming important as a multiple information source and gives an example of a GIS data and remote sensing data integration system which has reached the stage of practical use.

1.3.1 GIS (Geographic Information System)

(1) GIS

Research activities on the systematization of administrative land record information have been very active and many research papers have been published. The research topics include an urban information system, local information system and a municipal information system. A software package to facilitate such systematization has been marketed and actual data preparation has commenced in certain localities. These systems are characterized by their function of showing a map as well as letters and numerals as a victory graphics display and also the use of a plotter to output data. The actual function level, however, appears to largely vary from one system to another. The technology to process and display mapping information on a computer system was first established in the U.S. as the geographic information system (GIS) prior to Japan. At present, many such GISs are in use by municipal governments, central government agencies and private companies in the U.S. and Canada.

Geographic information system are computer-based systems that are used to store and manipulate geographic information (resources, urban factors, environment, forest and agriculture, etc).

The idea of the GIS started with the mesh method involving overlay analysis using geographic raster data. As seen in the case of National Landuse Information, this method handles various data more easily covering a wide area. Since the location of each pixel is represented in terms of row and column numbers, the computer has long been used to deal with the method. The polygon method was later invented to replace the rectangular cells of the mesh method which were a major shortcoming of the raster data model with polygonal cells. The only way to output polygon vector data in the early days was to use a plotter as the vector graphics display currently in use was not readily available. This polygon method greatly improved the reproduceability of mapping data but failed to maintain the various analytical functions associated with the mesh method. Some of today's polygonal processing systems, however have excellent analytical functions as a result of today have not only consolidated functions but also better operability.

The operation of a GIS involves the following 5 elements.

①	hardware	:	data input and output device; computer; data storage unit; graphic peripheral equipment; communication equipment
②	software	:	input driver software; geographic coordinate system software; database management system (DBMS) software; user interface (easy to use interface language; library; menu system); communication control software
③	data	:	spatial and attribute data generated by GIS software
④	processing method	:	contents of various processing methods such as statistical processing and graphic processing, etc.
⑤	expert	:	consultant versatile in GIS application in specialized field.

The core of the GIS function is the geographic coordinate system software of which the functions are largely classified into the following 4 categories.

① data input function
② data manipulation and analysis function
③ data management function
④ data output an conversion function

The data input function is very important for the creation of a GIS. A GIS with an excellent data structure is still a failure if it requires a lot of work to input or renew data. The data manipulation and analysis function means to express the contents of spatial analysis and, therefore, it necessarily requires data of encoding spatial relationships called topology. The data management function is essential when dealing with various types of data in large quantities. What this function does, for example, is to rearrange the geographic data of an entire city into man sections for easy handling and to store these data in DBMS. In the case of the data output and conversion function, it is important that the selection of map output, display or conversion to an external GIS can be easily made.

(2) ARC/INFO

1) Outline of ARC/ INFO

ARC/ INFO is one of the most popular GIS softwares and was developed in 1984 by the Environmental Systems Research Institute (ESRI) in California under the leadership of Scott Moorehouse who was engaged in the development of the GIS at the Computer Graphics Laboratory of Harvard University. ARC/INFO is the third generation GIS software developed on the basis of the first and second generation softwares in the 1970's (GRIND and PIOS respectively). As such, ARC/INFO has a much improved processing capability with faster speed and is applicable in many fields. At present, ESRI has more than 700 users in 37 countries, including the U.S., Canada, European countries, Australia and Japan.

2) Database Structure of ARC/INFO

ARC/INFO mainly consists of an ARC module which controls spatial data files and an INFO module (a relational database management system by HENCO of the U.S.) (Fig. 1-3-1).

ARC/INFO calls a set of data for each map a coverage and there are 5 types of coverages depending on shape, i.e. point, line, polygon, network (polygon and line) and link (line and point). Each coverage consists of such coordinate data as ticks (geographic control points), boundaries (maps boundaries), arcs, nodes and label points to control the spatial data.

An arc is a basic unit of the coordinate data, indicating the portion of line or polygon boundary and consisting of a node and segment. The crossing point of 2 nodes is automatically recognized as a node. An internal ID number is allocated to each arc or node to indicate the correspondence to attributes.

A coverage, such as a point or line, can immediately correspond to attributes. Additional data, however, are necessary in the case of polygon coverage. As shown in Fig. 1-3-2, polygon data consists of arcs representing boundaries and label points. The latter are used to show a representative point of a polygon and to show the relationship with the attributes of a specific polygon. Attributes can be made to an arc, label point, point and polygon. In the case of a polygon coverage, such attributes as internal ID numbers, boundary length, area and label point coordinates are automatically generated.

ARC/INFO uses an arc as a basic unit and defines the relative relationship of arcs vis-a-vis the spatial attributes in terms of topology. As shown in Fig. 1-3-3, an arc topology is given as a correspondence table of arc numbers and start/end nodes. Similarly, a node topology is given as correspondence table of node numbers and arc numbers while a polygon topology is given as a correspondence table of user ID numbers, internal ID numbers and arc numbers. Fig. 1-3-4 shows how various files, including a polygon topology, generated by a coverage can be managed. These files are automatically created through the man-machine dialogue. The contents of these files are described below.

ARC	:	arc coordinates file
LAB	:	label point coordinates file
TIC	:	tick coordinates file
BND	:	map extent coordinates file (the maximum and minimum coordinates of the map)
PAL	:	polygon topology
AAT	:	arc topology attributes file
PAT	:	attributes file
TOL	:	tolerance file

Fig. 1-3-5 shows the details of a PAT which is important in graphic data processing. INFO controls the attributes as a relational type DBMS. Such files as

TIC, BND, AAT and PAT, etc. created by an ARC are made on INFO and restored during the graphic data and attributes processing.

In short, ARC/INFO has a reliable database structure to perform its objective of managing and analyzing spatial data.

- Concept of Topology

Data expressing a spatial relationship (graph) are required to conduct a spatial analysis of a map using such spatial data as point, line and polygon while simplifying these data as much as possible. Topology is the concept to express these characteristics of a map in terms of the following 3 spatial relationships.

① area definition
② contiguity
③ connectivity

(a) Area Definition

A closed area can be expressed by multiple arcs which encircle the area as shown in Fig. 1-3-6. For example, the shadowed section of Fig. 1-3-6 is determined by arc numbers 1, 3, 4, 5 and 2. Arc 2 is separately dealt with to maintain the uniform relationship of the arc vis-a-vis the area and may be expressed as -2. In this way, an area can be expressed by the polygon-arc correspondence table and the arc coordinates

The advantage of this method is that data on arc coordinates need to be used only once while the arc numbers are repeatedly used to define the polygon. In other words, polygon data can be prepared by the simple input of arc data, reducing the volume of required data.

(b) Contiguity

This relates to the fact that a polygon is divided by arcs. The numbers circled in Fig. 1-3-7 indicate the polygon numbers. Arc 1 divides polygons①and②. If the left polygon number and right polygon number are given for each arc, the contiguity of a polygon can be expressed. Whether a polygon is on the right or left of an arc is decided by its relative position to the measuring direction of the arc. The important thing is that all polygons are determined as being either left or right based on the same principle.

(c) Connectivity

Arcs must be followed to determine the connections between polygons. An arc is defined as a section between the connecting points (nodes) or between a connecting point and an end (start) point. As a result, an arc can be expressed in terms of an arc and nodes. The previously called arc number corresponds to the arc portion. The connection between arcs can be expressed in terms of whether or not they share a node. With nodes (and points) being ID numbers, the connectivity can be expressed by topology data showing the relationship between an arc and the end /start points.

3) Functions of ARC/INFO

Fig. 1-3-8 shows the functions of ARC/INFO as an integrated system. The function of ARC/INFO to process spatial data and numerical data in factor consists of the following 4 functions.

① Data Input

- As arc data can be randomly input, automatically creating polygons, automatically creating polygons, the analysis speed is greatly improved.
- As input errors are easily recognizable on the display, they can be immediately corrected.
- There are many special features to maximize the input efficiency, such as the automatic creation of a node based on line data and the removal of an over-run arc.

② Analysis Function

- While many other systems restrict the scope of the analysis function, ARC/INFO is versatile in allowing the area calculation of a polygon, overlay of polygons, selection of a polygon, restructuring of a polygon and conversion of coordinates, etc. A wide range of applications is possible by combining these features.
- Spatial data, such as point, line and polygon data, are meaningfully connected with attributes and their mutual relationship is defined.
- A new polygon can be automatically generated by the overlay function.
- The system has a buffer function (function to automatically create a buffer zone) vis-a-vis spatial data.
- The connection and extraction of spatial data can be conducted for each map.
- The system provides compatibility between polygon data and mesh data.

- The system provides compatibility with data of other systems, including the DLG format (standard format from USGS).
- Various models can be created using the overlay function.
- The network processing capability provides the shortest route display and traveling time display, etc.

③ Database Function

- With the integration of the INFO system as part of the infrastructure, attributes which are important components of geographic data are efficiently handled on the display.
- As the data units are point, line, polygon and network, all geographic data can be handled.
- The map library function allows the random extraction of any area to make a temporary data file to improve the processing efficiency.
- The direct access method is adopted for the handling of files to improve the processing efficiency.

④ Data Conversion, Display and Output Function

- Spatial data are displayed in accordance with the indices
- Label points are automatically created.
- Many maps can be overlaid and displayed.
- Combined data can be overlaid and displayed.
- Shading of a polygon is available.
- Any display unit can be used provided it can accept the IGL output mode.
- The output of geographic attributes can be made in a tabular format by the DBMS function.

ARC/INFO has many other functions in addition to those described above. The polygon-overlay function is one of the most important functions of the system and creates a new map by 2 different maps for analysis purposes. For example, the overlay of a soil map and land ownership data creates soil data by land ownership categories. This function, which examines the relationship between 2 factors and creates a new set of data, is particularly useful in dealing with a large volume of data. It also allows the acquisition of such specific data as soil data, ownership categories and topographical conditions for a specific polygon. The overlay function is effective not only for a polygon but also for a point or line and their relationship is processed and analyzed for planning and/or decision making purposes.

Since many types of overlays, such as polygon-polygon, polygon-point and polygon-line, etc., are possible, data on climate, soil, vegetation, topography and water can be overlaid to determine their relationship. In short, the overlay of geographic data can create new sets of data for various purposes.

The buffer function is important in analyzing data. This function creates a buffer zone with a certain width vis-a-vis points, lines and polygones. For example, a buffer zone can be created against the point data of a well, a fireplug or a department store or the line data of a road, a river or a railway route to determine their relationship on a land use map.

Moreover, the use of the address matching function can identify the customers of a department store or bank by matching the addresses and streets. The identification of demographic distribution by income level is another possibility.

The network function using the relevant technology in the topology processing method enables route selection and location identification for automobile navigation.

Another function of the system which is the conversion of vector data to raster data (mesh) is also rather useful to integrate satellite image data or to convert vector data to image data (which are raster data).

In the addition to the functions described above, the system has a TIN (triangulated irregular network) as a support tool which observes the terrain surface as a set of interconnected triangular facets. The unique feature of a data model progressed by this TIN is that nodes, polygons and arcs are listed in tables to from triangles. The node table has a X and Y coordinates table and a Z coordinate table while the polygon table has data on slope direction. The arc table has slope direction and gradient data. These can be described as constituting a topological database. The use of these data can create various data with different use purposes. The TIN can assist in the preparation of a topological map (contour map), distribution of aspect direction map, sunshine conditions classification table or a perspective view.

The TIN allows the optimization of transportation routing, i.e. the selection of the optimal route based on the topographical conditions. This capability of the TIN suggest that various types of topographical analysis are also possible.

Fig. 1-3-9 and Fig. 1-3-10 show the function of ARC/INFO for better understanding while Fig. 1-3-11 shows the structure of geographic data to be stored in ARC/INFO using these functions.

1.3.2 Utilization of GIS

Concrete examples using the above-mentioned functions of a GIS are given below.

① Map Database

Such map entries as addresses, resident names and buildings etc. can be easily retrieved using a map number to facilitate the processing of enquiries at a public office.

② Retrieval of Specific Object on Map

Tourist information or town guide information can be retrieved by addressing a specific location on a map. The management of ground or buried facilities can be also conducted in the same way.

③ Statistical Data Processing

Such statistical data as national census results and statistical maps corresponding to addresses can be created and can them be combined with regional and resident data for marketing and other purposes.

④ Analysis and Assessment by Data Overlay

Data contained in various maps, statistics and documents can be combined into a single map and processed to prepare information for local planning.

⑤ Simulation

The results of various numerical experiments can be expressed on a map to assist local planning and other purposes.

(Application of GIS to Urban Planning)

Since the densities of such facilities as water, sewerage and rodes, etc. are dense in an urban area in addition to a highly dense population, the demand for a GIS is generally high. A system to meet the requirements under such conditions is outlined in Fig. 1-3-12. The same system can also be applied for a landuse plan, forest management plan and water resources management plan, etc. A concrete example of its application to a landuse plan is shown in Fug. 1-3-13 which features Gushikawa and Okinawa in Okinawa Prefecture as the model area (scale: approximately 1/150,000). Using the buffer function, the current landuse conditions in zooms of 50m, 100m and 200m on both sides of national, prefectural and municipal roads are shown.

(Application of GIS to Disaster Prevention Plan)

The disaster risk of a local area was assessed by adding the social conditions, including the degree of urbanization and paster disaster history, to the natural conditions, such as topographical and geological and geological conditions, in order to prepare prior measures to prevent or to alleviate damage caused by such disasters as earthquakes. The data used for the assessment were as follows.

- location of possible epicentre of an earthquake and its magnitude
- distribution of areas vulnerable to earthquake damage due to topographical and/or geological reasons; distribution of areas with high population and facility concentration
- records of disaster occurrences in the past

The landuse data indicating landuse categories as former swamps and landfilled streams, etc. which are vulnerable to earthquake damage were overlaid on a map to determine the danger areas and a quantitative evaluation was conducted to determine the possible damage ratios of buildings, roads and underground pipes, etc. in these areas. Fig. 1-3-14 (scale: approximately 1/2,500,000) shows the geological conditions, assessed degree of disaster risk and distribution of estimated seismic intensity.

1.3.3 Integration of Digital Image Data (Raster Data) and GIS Data

Here, a system to integrate digital image data and GIS data is described using the ERDAS software jointly developed by ERDAS of the U.S. and the Georgia Institute of Technology as an example of a digital image processing system.

Data processing to integrate digital image data and vector type GIS data can use one of the following 3 methods.

① Transfer from GIS Data File to Image Data File

When an ARC/INFO coverage is converted to a raster type GIS file for ERDAS, spatial data are converted to grid (pixel) data. One of the attributes of the coverage is selected as the class value for the new raster type GIS file for ERDAS as the latter can only retain one class value as the attribute.

Application Examples:

1. Municipal coverage data obtained from the National Landuse Information can be converted to create a masking image based on voluntary boundaries.
2. A landuse coverage obtained from the landuse information or an existing GIS map can be converted to conduct a statistical analysis of the spectra values of the landuse categories. The analysis results are then compared with the statistical values of a training area which is selected for the supervised classification process.
3. An ARC/INFO coverage can be converted to conduct image processing using the classification process or level slice process for each classified area for analysis and assessment purposes.

② Transfer from Image Data File to GIS Data File

When the image processing results by ERDAS or analysis results of raster type data are converted to a coverage, spatial data are changed to polygon data while geocoordination data are preserved. A class value of ERDAS is automatically registered as an item called a grid code in the attribute database of the GIS.

Application Examples:

1. The classification results using the supervised classification or cluster method can be converted to a coverage to prepare a thematic map which can be added to the database to reinforce its strength.
2. A highly accurate or useful thematic map of a desert or undeveloped area can be prepared using the remote sensing data and the map output function of ARC/INFO.

③ Linkage of Two Systems

In conducting geometric correction, ERDAS can provide geocoordination data in line with a specific map project method for geometrically corrected image data by designating the use of the identical map projection method, coordinates and pixel sizes used by the coverage to which it is linked. With the execution on the ARC/INFO side of a command to coincide the display scale and coordinates with those of the image data, a highly accurate overlay of vector data on raster data is made possible.

Application Examples:

1. When the location of disasters or landuse changes following landslide, flooding, felling or opening of a motorway can be clearly identified by visual interpretation, updating and editing of the database can be swiftly and accurately conducted by digitizing new data on the graphic display using images as background.
2. A coverage obtained by GIS analysis can be overlaid on the display image of an existing map, the input of which is made by the image scanner device, to evaluate the GIS analysis results.

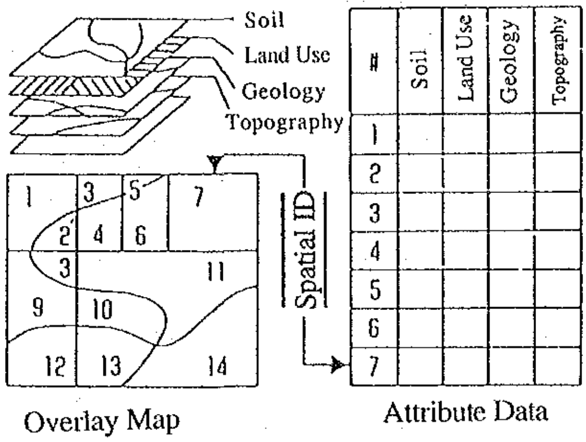


Fig. 1-3-1 Concept of ARC/INFO Data Model

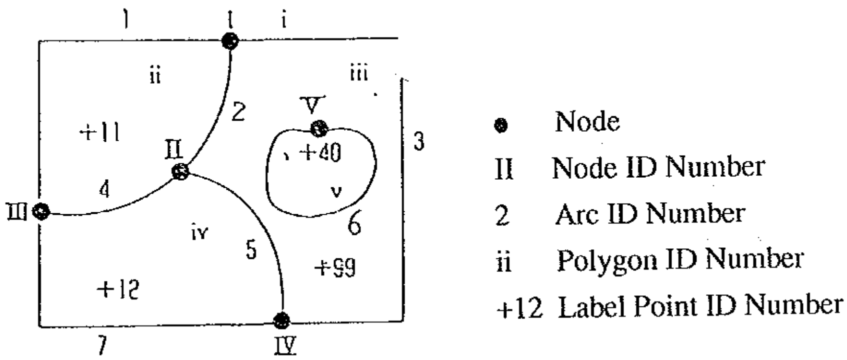


Fig. 1-3-2 Contents of Map

Polygon Topology

User-ID	Polygon #	Arc #
	i	1,3,7
+11	ii	1,2,4
+99	iii	3,5,2,0,6
+12	iv	5,7,4
+40	v	6

Node Topology

Node #	Arc #
I	1,2,3
II	2,4,5
III	1,4,7
IV	3,5,7
V	6

Arc Topology

Arc #	From Node	To Node	Left Poly	Right Poly
1	I	III	ii	i
2	II	I	ii	iii
3	I	IV	i	iii
4	II	III	iv	ii
5	II	IV	iii	iv
6	V	IV	iii	v
7	IV	IV	iv	i

Fig. 1-3-3 Structure of Mapping Elements

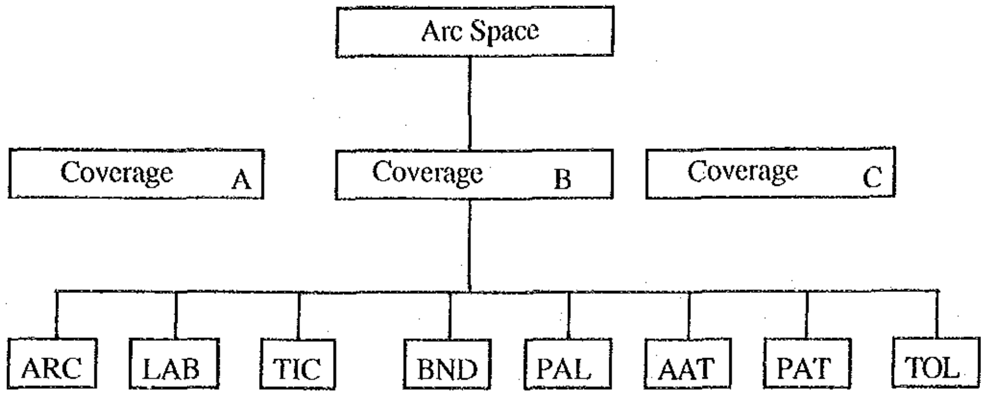


Fig. 1-3-4 Style of File Management

Area	Circumferential	Coverage Internal ID. No.	User ID No.	Geology	Vegetation
21.450	3.457	2	1		
.	.	.	.	.	.
.	.	.	.	.	.

Fig. 1-3-5 File Contents

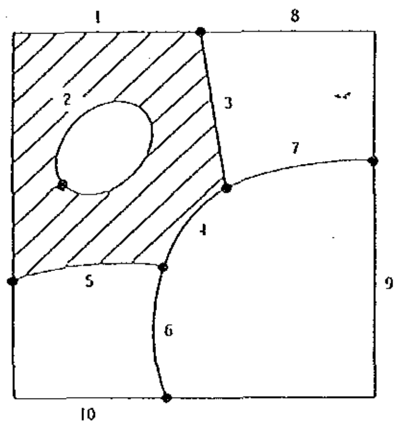


Fig. 1-3-6 Area Definition

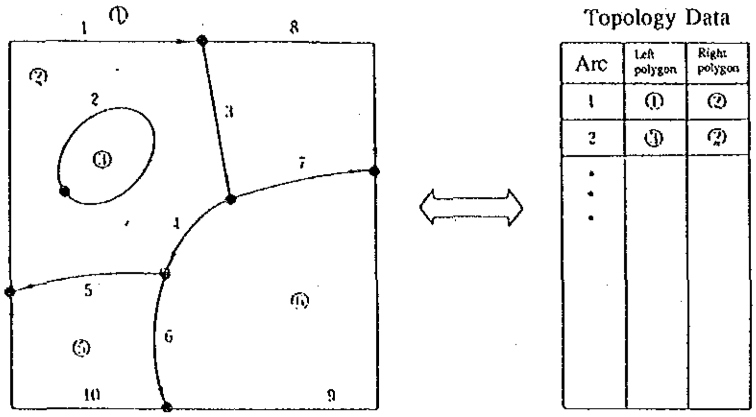


Fig. 1-3-7 Contiguity

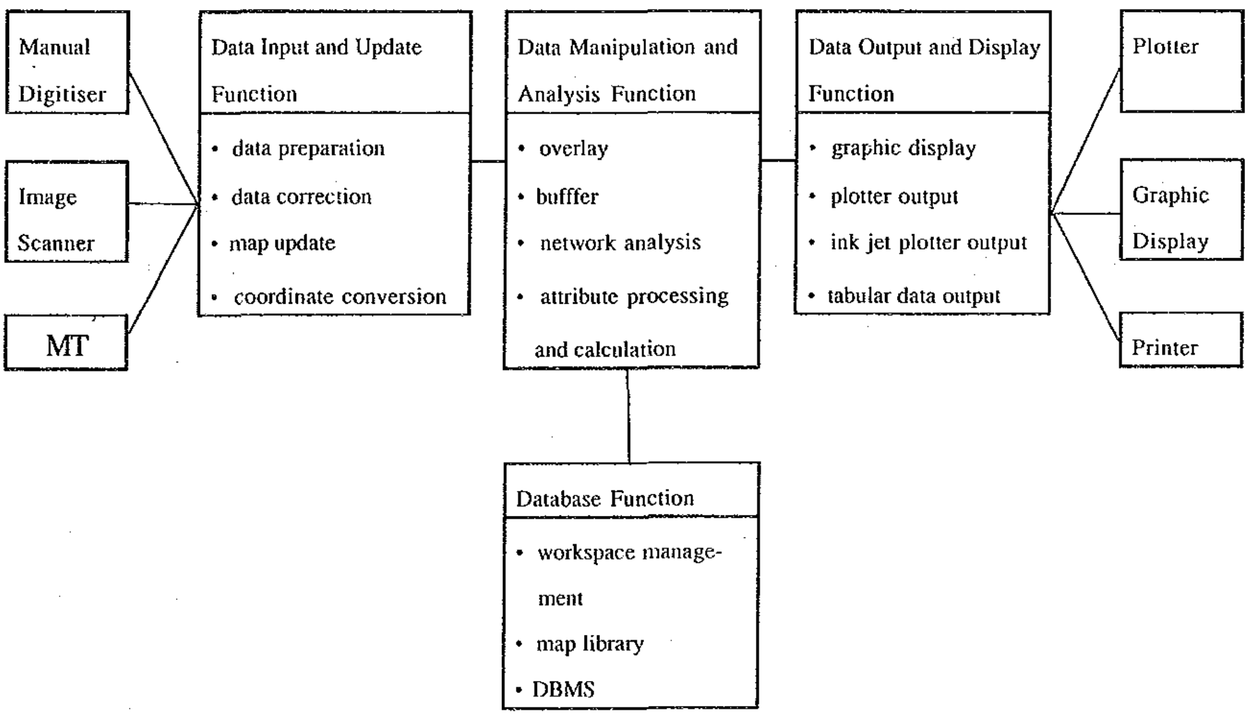
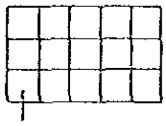


Fig. 1-3-8 Main Functions of ARC/ INFO

(Input and Output Functions)

Function	Description	Application
Polygon Input	1) input of coordinate data  2) reading of boundaries by digitiser; area marked by dotted line is read only once	• distribution map, boundary map or building where line and area presentation is required • where high data accuracy is required Examples: topographical, soil or vegetation map; designation of area subject to legal regulation
Grid Input	1) input of attribute data  2) input of attribute data written in voluntary format on a card	• where designation of boundaries or distribution is impossible or rough processing of data Examples: meteorological data; topographical classification; elevation

(Processing Function)

Conversion of Data to Symbols	1) output of attribute data made in the form of symbols	

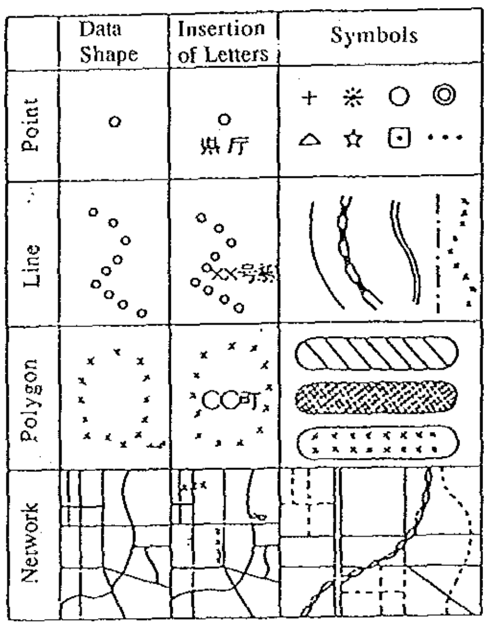


Fig. 1-3-9 Functions of ARC/INFO

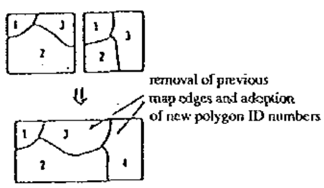
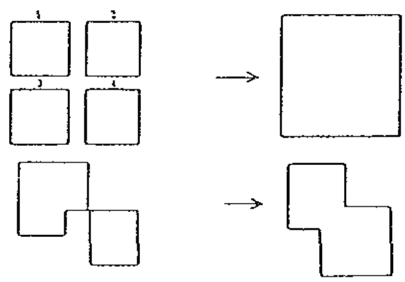
Function	Description	Application
a) Data Select and Search	1) data selection using database 2) enlargement of specific area of map  3) search of voluntary shape  point, polygon, square, circle	o selection based on attributes : list of towns with population of (say 10,000) or more o selection based on coordinates : check of coordinates constituting municipal boundaries of (say, Tokyo) o selection and enlargement of specific area to check locations of various amenities o search of area of 500m radius around public facility
b) Measurement, Calculation and Statistics	1)measurement of point locations  2) measurement of line  3) measurement of polygon 4) volume calculation 5) statistical calculation 6) arithmetic operation between attributes	o determination of number of particular facilities in one district o calculation of aggregate distance o calculation of aggregate length of water/sewerage network o calculation of landuse area o calculation of earth work volume o calculation of average, standard deviation and occurrence by category, etc. o addition of field area of landuse data to road area of road data
c) Map Join	1) joining of maps 	o input of separate polygons for their integration in computer (different polygon shapes can be input 

Fig. 1-3-10 Functions of ARC/INFO (1/4)

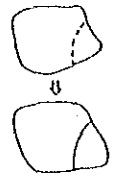
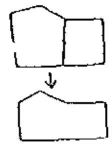
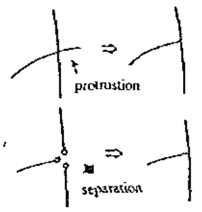
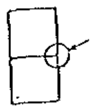
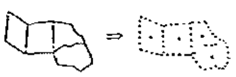
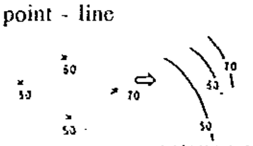
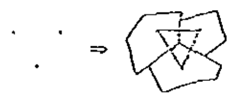
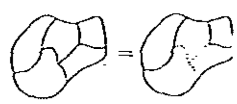
Function	Description	Application
d) Polygon Data Correction	1) addition of a line 	o changes of administrative boundaries
	2) removal of a line  to make a single polygon	o merger of administrative districts
	3) correction of an arc  	o correction of input error  correction of errors which tend to occur at places like this
e) Polygon Conversion	1) Polygon - point 	o determination of administrative centre from administrative boundary data and attachment of all attributes to this centre point; calculation of distance between 2 town centres
	2) point - line  contour line	o calculation of ppm values to indicate degree of air pollution; drawing of contour lines (calculation of area with elevation of 50m or less)
	3) point - polygon 	o estimation of regional rainfall based on rainfall data given by rain gauges
	4) polygon - polygon  (following change of category)	o creation of new polygon indicating land use category by changing designated categories of neighbouring areas o output to conduct landuse assessment through trial and error method

Fig. 1-3-10 Functions of ARC/INFO (2/4)

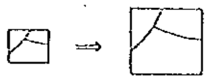
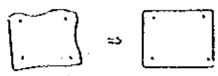
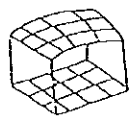
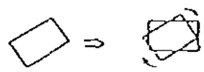
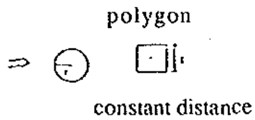
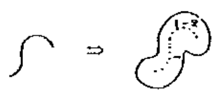
Function	Description	Application
		o eradication of former boundaries when new population densities of 2 areas show same value
f) Map Projection	1) change of scale 	o enlargement or curtailment of scale for overlay purposes
	2) distortion correction 	o correction of bent boundaries to avoid errors in map joining operation
	3) change of projection method 	o adoption of same projection method to overlay a map with a scale of 1:50,000 with that with a scale of 1:200,000
	4) rotation and shifting 	o syncronization of north direction of 2 maps
g) Buffer	1) point 	(creation of specific polygon) o search of area of 1km radius from prefectural office
	2) line 	o search of 500m wide zones on both sides of road
	3) polygon 	o study of landuse in 1km belt outside urbanised area

Fig. 1-3-10 Functions of ARC/INFO (3/4)

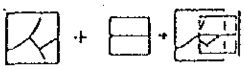
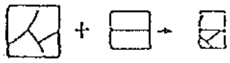
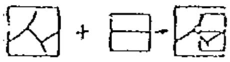
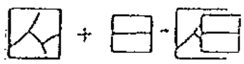
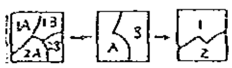
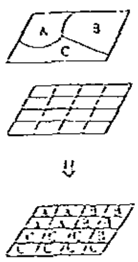
Function	Description	Application
h) Overlay	1) Union 	o overlay of administrative area on data of designated area
	2) intersect 	o display of only overlapping areas of above
	3) clip 	o overlay of above 2 areas but compilation in one area only
	4) update 	o insertion of one set of data to another
	5) reorganization 	o reorganization of data based on a specific attribute
i) Grid Conversion	1) grid conversion 	o overlay of National Landuse Information data on municipal data

Fig. 1-3-10 Functions of ARC/INFO (4/4)

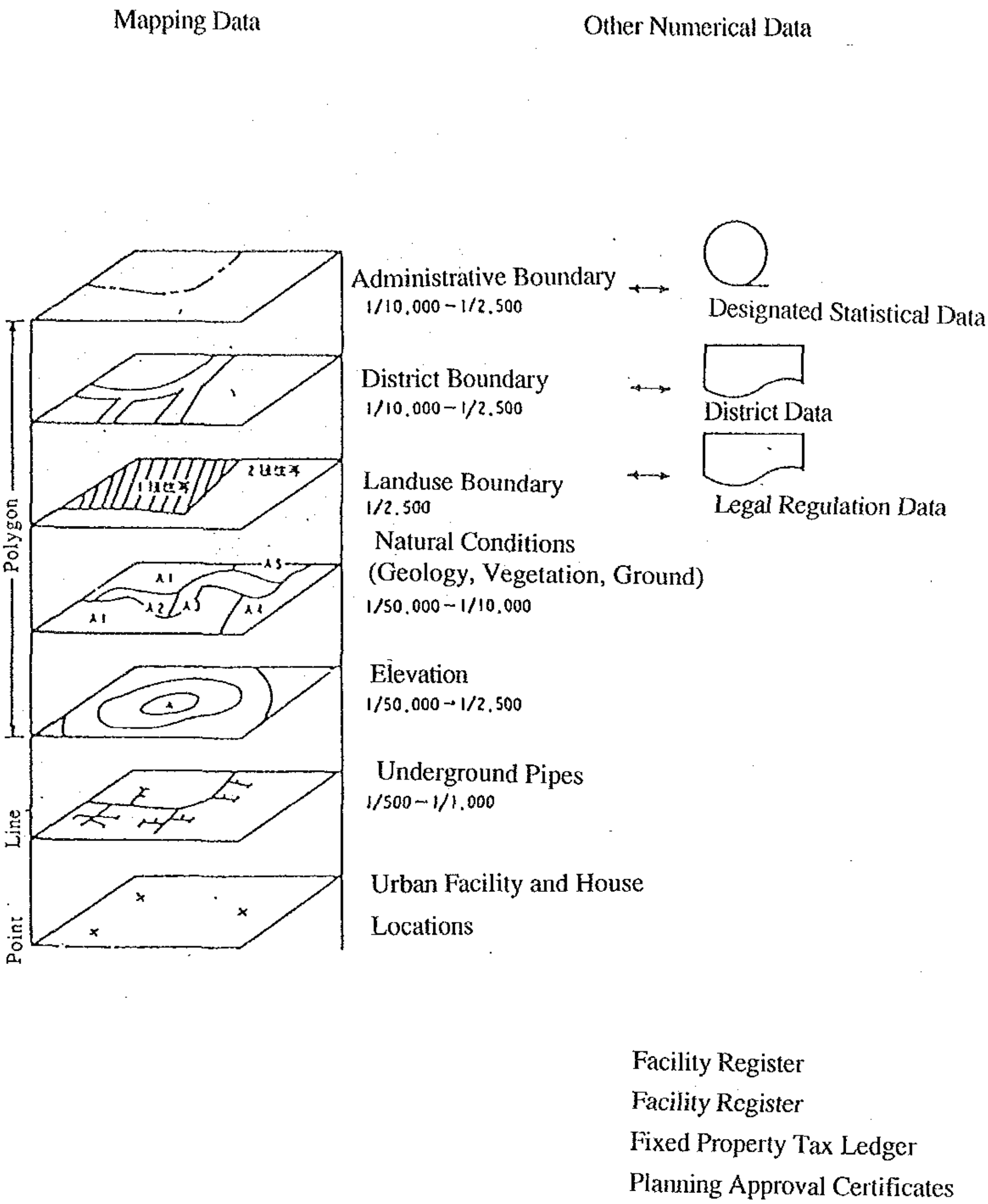


Fig. 1-3-11 Structure of Mapping Data (Point, Line and Polygon)

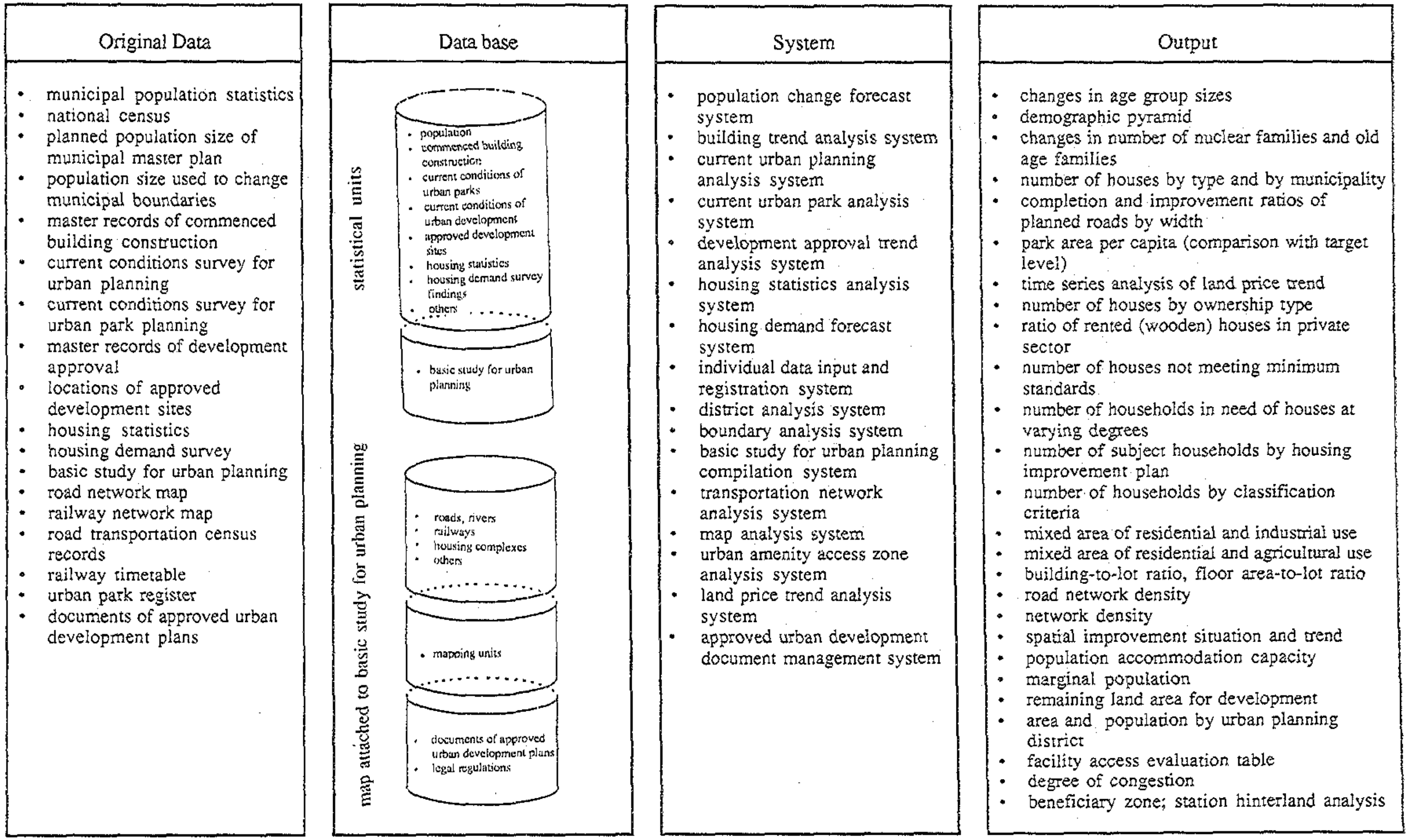
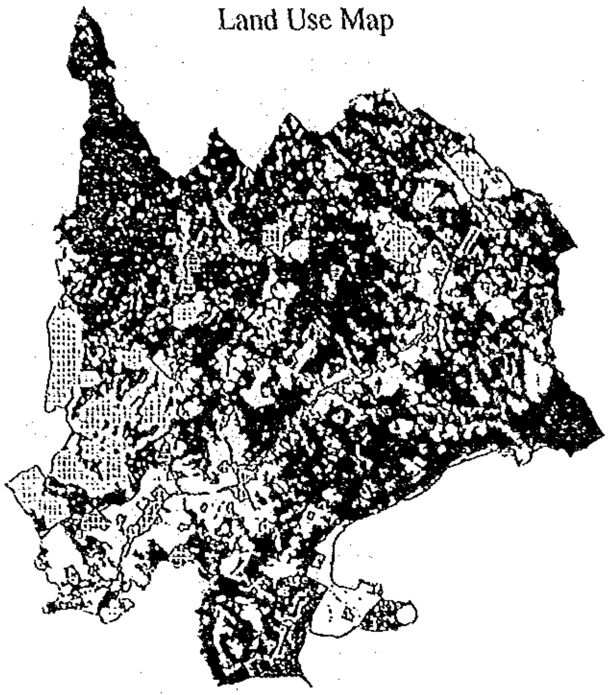
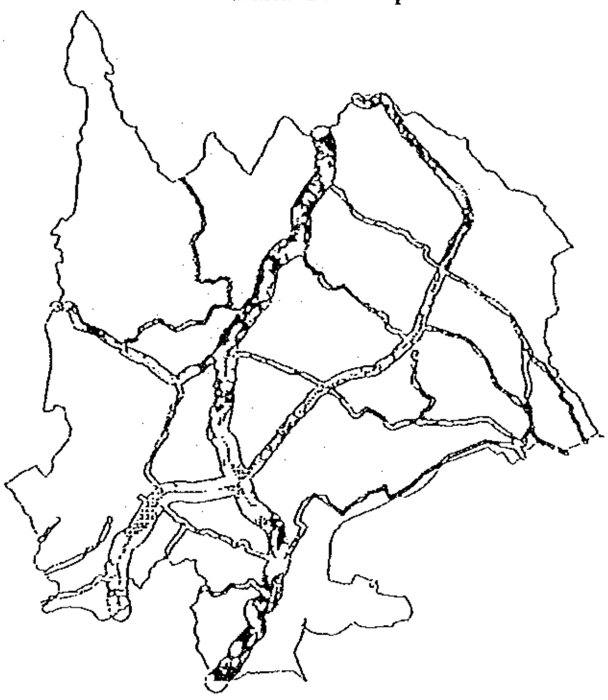


Fig. 1-3-12 Outline of Urban Information System

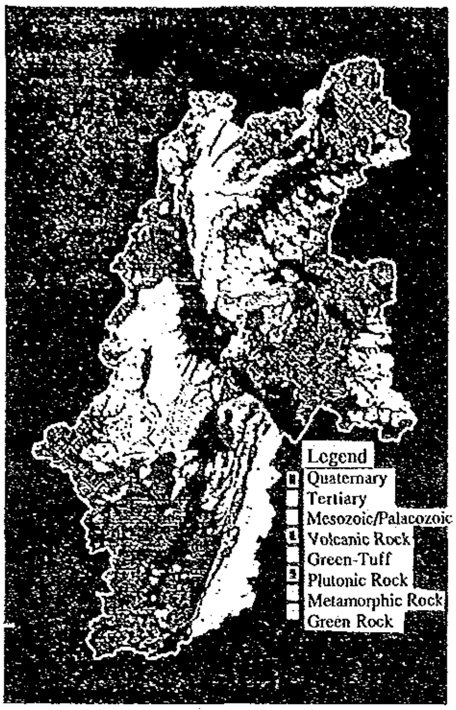




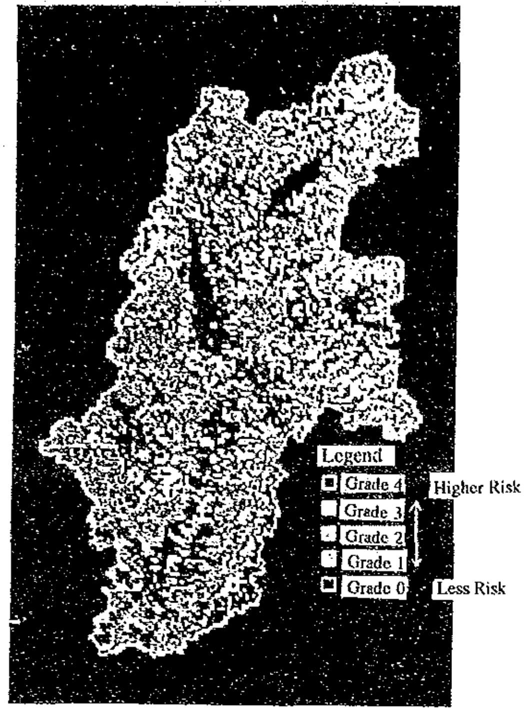
Land Use Category	Area	%
Paddy Field	18514	0.1
Cultivated Field	3536087	26.4
Orchard	4301	0.1
Forest	1237095	9.2
Wasteland	1533894	11.5
Water	88076	0.7
Residential Area	4517260	33.7
Factory Site	131438	1.0
Office Site	1269342	9.5
Public Facility Site	248226	1.9
Recreational Site	76324	0.6
Vacant Land	122242	0.9
Military Base	589990	4.4
Total	13372789	100.0

Paddy Field
Cultivated Field
Orchard
Forest
Waste Land
Residential Area
Factory Site
Office Site
Office Site
Public Facility Site
Recreational Site
Vacant Land
Military Base

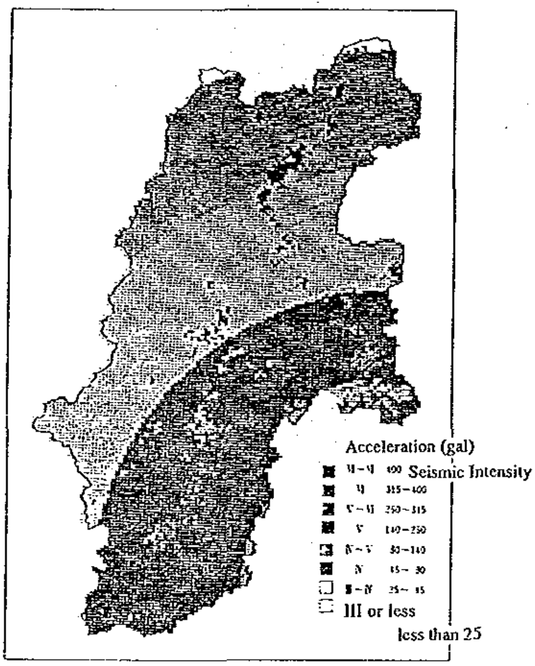
Fig. 1-3-13 Land Use Map (Gushikawa and Okinawa)



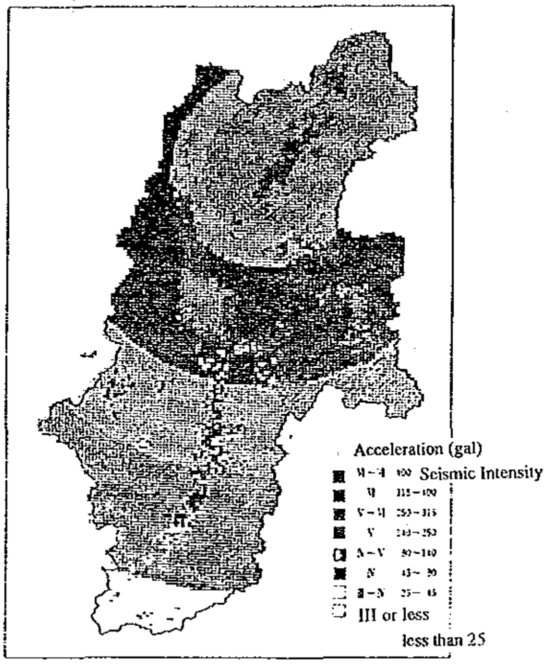
Geological Map



Landslide Disaster Risk Assessment Map



Estimated Seismic Intensity Map (Tokai Earthquake)



Estimated Seismic Intensity Map (Zenkoji Earthquake)

Fig. 1-3-14 Earthquake Damage Assessment

(Glossary)

GIS (Geographic Information System)	:	tool to manage various local geographic data and to manipulate spatial data using the relationship between maps and attribute data.
ARC/INFO	:	one of the most popular GIS softwares developed by ESRI of the U.S.
Coverage	:	data for one map
Arc	:	basic unit for coordinate data
Node	:	meeting point of 2 arcs
Boundary	:	map boundary
Tick	:	control point for coordinates for each map
Polygon	:	polygon figure
Label Point	:	pointing in a closed figure requiring addition of attribute data
Topology	:	relationship between spatial data
DLG Format (Digital Line Graph Format)	:	format for data supplied by U.S. Geology Survey Institute
Overlay	:	overlay processing of multiple maps
Buffer	:	function to create a zone with a certain width vis-a-vis point, line or polygon
Network	:	analytical processing, such as selection of shortest route and others
ERDAS (Earth Resources Data Analysis System)	:	one of the most popular image analysis systems developed by ERDAS of the U.S.
Raster Type GIS	:	a raster type GIS does not normally assume the processing of vector data and allows overlay and buffer functions using mesh data.

1.4 Production of Thematic Map Using Remote Sensing Data

Yukio Mukai

A thematic map usually means a map which is based on a certain theme (objective), such as a land use map or a vegetation map and, therefore, there are many different kinds of thematic maps. Thematic maps which can be produced by remote sensing data are as follows.

- land cover classification map
- vegetation distribution map
- water region distribution map
- snow region distribution map
- contour map (digital elevation model)
- sea surface temperature map

In addition to the above maps which can be directly produced by remote sensing data, there are also other thematic maps which can be produced from the above maps based on inference or interpretation together with the use of other reference materials. For example, a land use map can be produced from a land cover classification map. Moreover, another type of map called an evaluation map exists. An evaluation map is produced to evaluate a specific item by using a number of thematic maps and other topographical information and taking into account the weighting factors of the thematic maps. A land productivity evaluation map can be produced from a vegetation map, a water region classification map and a soil map. In fact, the evaluation map is a target map and thematic maps using remote sensing data are produced in the process of producing the evaluation map (or maps).

A critical question in the process of producing a thematic map using remote sensing data is how to present the data in manner which can be easily understood and utilized. Two methods are commonly used to facilitate such understanding and utilization. One is image display and the other is map display.

- Image Display

This involves the direct display of a resulting image based on remote sensing data. Image output is made in terms of a photograph using an image recorder or a paper print-out using an image output device such as an ink jet printer. Although image display is easy to achieve, it is not easy to use. Overlay output of an image with an existing map could make it easier to use.

- Map Display

This involves the delineation of the surrounding area of a thematic image obtained from remote sensing data to produce it in map form. This type of display is generally much easier to understand and use. However, an optimal method to effectively reproduce data classified in terms of minute pixels in the form of geographic information has not yet been established. Since development efforts to integrate a GIS (geographic information system) into remote sensing data processing are actively underway, their subsequent completion will solve the problem of achieving the maximum reproduction of remote sensing data in map form.

1.4.1 Land Cover Classification Map

A land cover classification map shows the classification results of land cover using multispectral data obtained by remote sensing and is one of the basic thematic maps produced from remote sensing data. Many other thematic maps can be produced based on this map. The map can be produced by setting land cover categories and by following the procedure of multispectral classification described in 1.1. Land cover categories which can be used based on remote sensing data are as follows.

> high density urban area, urban area, residential area, large building/structure, bare soil, wasteland, golf course, grassland, cultivated field, paddy field, broad-leaf tree, needle-leaf tree, river water, seawater

1.4.2 Vegetation Distribution Map

There are two methods to produce a vegetation map.

- multispectral classification method
- vegetation index method

(1) Multispectral Classification Method

This involves the setting of some vegetation categories and the conducting of multispectral classification selecting training areas for the categories. Appropriate classification categories should also be established to denote non-vegetation areas such as urban area, residential area and water region etc.. A vegetation map can be produced by extracting areas of vegetation categories from the above multispectral classification results. Since the spectral reflectance characteristics of vegetation change seasonally, the vegetation classification accuracy can be improved by combining data for different seasons, for example, rainy and dry season data for a tropical zone or summer and winter data for a temperate zone.

Vegetation categories which can be used based on Landsat TM data are given below as examples.

paddy field, grazing grassland, grassland, broad-leaf tree, pine, Abies veitchii cedar, cypress, fir

These are categories which are applicable in the case of Japan which is located in the temperature zone. The introduction of such detailed classification for the tropical zone, which includes Indonesia, may be difficult.

(2) Vegetation Index Method

These spectral reflectance intensity of plants is low in the visible red region (0.63 - 0.70μm) and high in the near infrared region (0.7 - 1.1μm) as shown in Fig. 1-1-2. This is caused by the absorption of red light by chlorophyll inside plants and the reflectance of near infrared light by active photosynthetic substances. With the use of the following equation to indicate the vegetation index value (VI), the vegetation area can be emphasized for classification purposes.

$$VI = \frac{D_{IR} - D_R}{D_{IR} + D_R} \qquad (1.4.1)$$

D_{IR}: reflectance intensity in near infrared band

D_R: reflectance intensity in visible red band

The data to be used are Band 3 of Landsat TM data or Band 5 of MSS data for D_R and Band 4 of TM data or Band 6 or 7 of MSS data for D_{IR}. As the value of VI is high for a vegetation area, the selection of areas with a VI value above a certain level can produce areas covered by vegetation although the types of vegetation cannot be identified as in the case of the multispectral classification method. As the VI value has strong correlation with biomass, it is effectively used to estimate the biomass volume. VI values based on NOAA data are also available, providing a useful data source for the global scale monitoring of vegetation changes.

1.4.3 Water Region (Water System) Distribution Map

The reflectance intensity of water is generally low throughout the entire wavelength regions but is slightly high in the visible blue and green, regions and extremely low in the near infrared region. A water region can be easily delineated by extracting dark areas in the photo interpretation process using false color images and similar images. When it is difficult to distinguish a water region from a dark area like a shadow, photographs using the ratio of blue/green band and the near infrared band (MSS4/MSS7, TM1/TM4) should be used for comparative interpretation. A dirty water area has a high reflectance intensity in the visible blue and green regions and is not necessarily dark on a false color image but is shown in a color with a strong tint of blue/green. In this case, data on the boundaries between water regions and land should be referred to.

A water system distribution map can also be delineated by the visual interpretation of false color images.

1.4.4 Snow Region Distribution Map

A snow region is shown in white on a false color image and is an easy subject for visual interpretation. While its differentiation from a cloud is difficult, it can be done using the following methods.

- In the case of Landsat TM data, data on the intermediate infrared region (Bands 5 or 7) should be used. The reflectance intensity of snow in this region is smaller than that of a cloud.

- In the case of images using only the visible light region or the near infrared region, a shadow occurs near a cloud. This shadow can be used to differentiate between a snow region and a cloud. However, a cloud in a mountain range may not create a shadow due to its low altitude vis-a-vis the ground surface, making it difficult to differentiate between a snow region and a cloud.

1.4.5 Contour Map (Digital Elevation Model)

At present, data on topographical undulations are expressed on a map by contour lines. When these data are expressed in the form of three dimensional data consisting of the grid position on the x and y coordinated and the elevation of the position (z), the structure is called a digital elevation model (DEM). Topography expressed in the form of a DEM makes the computer production of a contour map, land profile map, an landscape easy and is very effective for the evaluation of a land development project and arable land survey, etc. A DEM can be made using the following 3 methods.

- topographical map interpretation
- stereo aerial photograph interpretation
- stereo satellite image interpretation

While topographical map interpretation is the easiest method, it can take a long time to cover a wide area. This method cannot be used without a ready-made topographical map. Stereo aerial photographs usually provide data for topographical map production and a detailed DEM of an area for which no topographical map is available must be made on the basis of stereo aerial photographs.

Since the successful launch of the SPOT 1 in 1986 which has an oblique viewing capability, the method of using SPOT stereo data to make a DEM has gradually proved very effective. The method to read topographical map data has already been described in the Technical Manual for Phase I and only the method to use satellite data is explained below.

(1) Basic Principle of Elevation Computation Based on SPOT Data

The basic principle of computating the elevation of part of the earth's surface using SPOT data with 2 different view angles is illustrated in Fig. 1-4-1. SPOT L and R indicate SPOT positions when point P on the earth's surface is observed from the left and right sides respectively. Assuming a datum plane for elevation computation, an image is produced where the observation images from the left and right are overlaid on the datum plane. A datum plane should offer many control points (datum plan GCP) which have the same elevations on different images for overlaying purposes. With 2 images overlaid on the datum plane (called stereo images), point P with an elevation of H_P is located at L_L on the image observed from the left or at L_R on the image observed from the right, causing parallax L_D. The elevation H_P can be given by computing the value of this L_D. Firstly, L_L and L_R are determined by searching the corresponding points of P between stereo images. By using the SPOT location when P was observed, the SPOT altitudes H_L and H_R and the distance (L_B) between the center lines of the 2 observation images are given. The use of system collected data ensures that the nadir point of the satellite is directly above the center line of the image. The elevation H_P of point P is finally given by the following equation.

$$H_P = \frac{L_L + L_R - L_B}{L_L/H_L + L_R/H_R} \qquad (1.4.2)$$

(2) DEM Preparation Procedure Using SPOT Data

The elevation computing method described in (1) above addresses the case where 2 planes containing the satellite position and the straight line between the satellite and the corresponding point are on the same vertical plane and considers the datum plane to be flat. In reality, however, the 2 planes are deviated by 2 - 3° and the datum plane is not flat but spherical. Therefore, it is necessary to obtain the corresponding points and satellite position in three dimensional Earth Center Rotation (ECR) coordinates. In addition, the crossing point of the 2 lines connecting the satellite and the corresponding point must be computed in a three dimensional manner. Fig. 1-4-2 shows the DEM preparation procedure by computing the elevation of the earth's surface in a three dimensional manner using SPOT data. Refer to reference material 1) for a more detailed explanation of the procedure.

(3) Production of Contour Map

When a DEM has been established, a contour map can be automatically computed and printed out by a X - Y plotter or other devices. Softwares to produce a contour map using a DEM are already being marketed for use with personal computers.

1.4.6 Sea Surface Temperature Map

The intensity of radiant energy from the earth's surface, the average temperature of which is 300°K, is strongest in the wavelength band of 10.5 - 12.5μm. By measuring the intensity of radiant energy in this band, the temperature of an observation subject can be given (this band is called a thermal band). Landsat TM, MOS-1/VTIR and NOAA/AVHRR data contain a thermal infrared band and the temperature of the ground (sea) surface can be determined by using these data. Since thermal infrared band data are based on the intensity of radiat energy from a subject rather than on the intensity of the reflectance of sunlight as in the case of the visible light band and near infrared band, the energy intensity is very weak, making fine ground resolution difficult to obtain. As a result, thermal infrared band data are mainly used for the observation of the sea surface temperature distribution where relatively rough resolution does not pose a serious problem. One problem in the production of a sea surface temperature map is how to correct the atmospheric attenuation between the sea surface and the satellite. There are 2 atmospheric correction methods as given below.

- regression method
- split window method

(1) Regression Method

A regression equation between satellite data and real sea surface temperature data (sea truth data) can be obtained by the least square method using simultaneously observed satellite data and sea truth data on several points. Once this equation has been obtained, satellite data can be converted to sea surface temperature data using this equation. This method involves a difficulty in that the sea truth data must be collected simultaneously with the satellite data in the several points.

(2) Spilt Window Method

The largest atmospheric attenuation is caused by water in the atmosphere. The thermal infrared band can be divided into two bands of 10.5 - 11.5μm band and 10 11.5~12.5μm band. The attenuation by water in atmosphere is slightly larger in the case of the latter than in that of the former. Using this fact, the observation results on these 2 bands can be used to infer the water content level in the atmosphere based on which the atmospheric attenuation can be corrected. This method is called the split window method and an example of an atmospheric correction equation using this method (cited from Reference No. 2) is given below.

$$T_s = T_{11} + \alpha\ (T_{11} - T_{12}) + \beta \qquad (1.2.1)$$

T_s : corrected sea surface temperature

T_{11} : brightness temperature of 10.5 - 11.5μm band

T_{12} : brightness temperature of 11.5 - 12.5μm band

α, β : constants: $\alpha = 1.395$, $\beta = 0.363$

The above constant values were obtained by the regression equation using the typical sea surface temperatures of 5 atmospheric models representing the tropical zone, middle latitude zone and subarctic zone, etc. (see Reference No. 2 for more details). The split window method is convenient as it does not require sea truth data. However, whether or not the model with constant values fits the atmospheric model of the subject area for sea surface temperature distribution must always be checked.

References

1) Y. Mukai, T. Sugimura and K. Arai, "Generation of Digital Elevation Model Using System Corrected SPOT Data", Proceeding of ISPRS Com. IV, 1990.

2) S. Takeuchi, M. Kano, K. Watanabe, Y. Maeda, H. Wakabashi and S. Ogawa. "Atmospheric Correction of MOS-1/VTIR Data by Split Window Method", Collection of Papers Submitted to 8th Seminar of Japan Remote Sensing Society, pp 115 - 118, 1988.

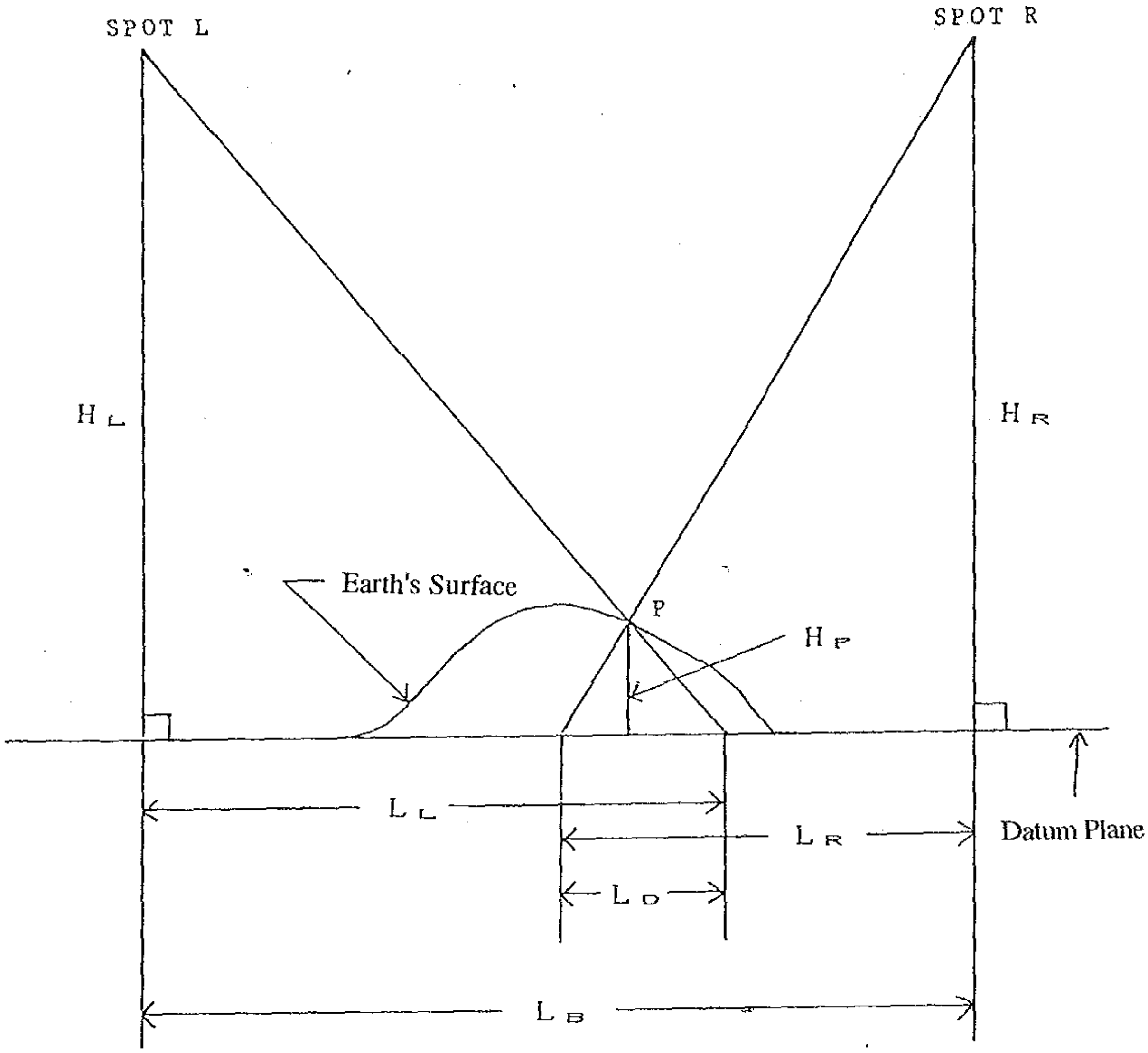


Fig. 1-4-1 Principle of Computing Elevation of Earth's Surface Using 2 Sets of SPOT Data with Different Viewing Angles

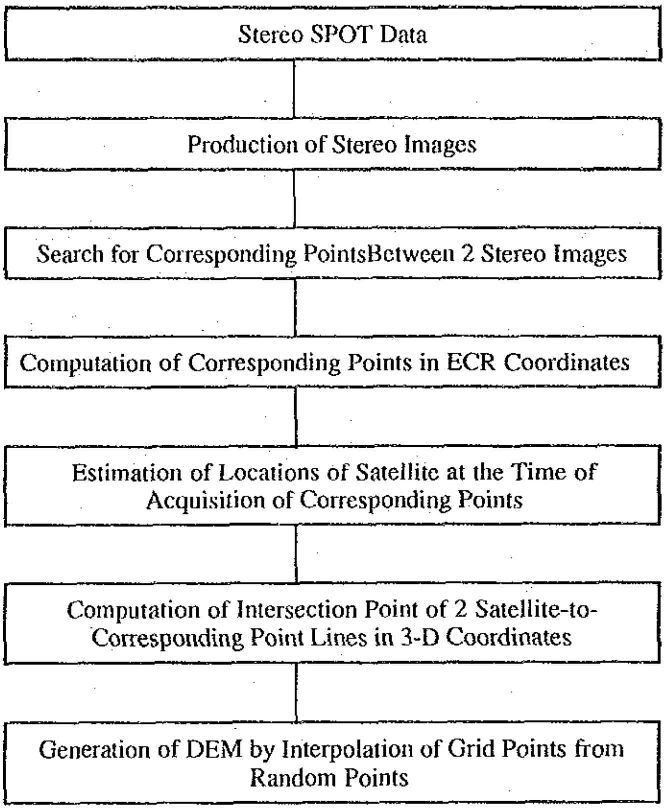


Fig. 1-4-2 Production Procedure of DEM from SPOT Data

1.5 General Introduction to Remote Sensing Database

Yoshizumi Yasuda

Introduction

The storage and utilization of a large volume of data has become increasingly easy in recent years due to the development of the low price, large capacity, random access magnetic disk and also due to the development of the rewritable opto-magnetic disk. At the same time, the demand for the integrated processing and storage of diverse data has been particularly strong for remote sensing and geographic information systems (GIS). In the case of resource management or assessment for example, the data themselves are becoming more important than the data processing function. Data are common property and the requirements for their joint use for useful purposes and their security management are the starting point for the creation of a database. The creation of a database has many advantages, namely, (1) common use of data, (2) easy production and alteration of application programmes and (3) integrated management of and reference to data which are generated independently within an organization.

To understand the concept, functions and objectives of a database, it is useful to compare the characteristics of a database with those of a file in conventional data processing. In 1.5.1, the concept of a database and functions of a database in a GIS and remote sensing are explained by examining such basic characteristics of a database as the common use of data, integrated data management and independence of data.

The 4 types of human environments surrounding a database, i.e. end user, application programmer, database administrator and organization representative, are explained in 1.5.2 to assist the further understanding of a database system. It is essential for any database to store data for easy access and application. A data structure and hierarchy assisting such access to and application of data are also explained in 1.5.2 together with a database structure, data models and a distributed database system of which understanding is essential for any further discussion concerning database in general.

1.5.3 deals with a remote sensing database with explanation on remote sensing/GIS/ database.

1.5.4 deals with the processing environment of a database where a system can become antiquated in 3 years due to the all too rapid progress of computer technologies. The main topics are an open type distributed processing system and user interfaces which should become important features in the processing environment in the 1990's. A likely processing environment for Phase II of the Remote Sensing Engineering Project for the Development of Agricultural Infrastructure in the Republic of Indonesia is also discussed to conclude this chapter. As the chapter intends to explain the general concept, characteristics and basic ideas for application, it does not address any specific database.

1.5.1 Functions (Objectives) of Database

1.5.1.1 Concept of Database

The term database first appeared in the late 1960's. Although its origin has not been clearly identified, it may have meant a supply base for data based on the association of the word "base" with a military base. Databank is a synonym.

The purpose of using a computer is nor only to compute but also to make it conduct routine processes. As a result, a computer is required to not only process and compute data but also to store data. In the case of resource management or environmental management using remote sensing data, data rather than the processing function is important. Here, data for common use must be stored in such a way as to allow easy access and application. Moreover, data and their structure must be protected from arbitrary alteration or destruction.

The concept of database originates from the common understanding that data are common property and the user requirements for the effective utilization and safe management of such common property have been the driving forces in the creation of a database.

Comparison between a database and a file in conventional data processing facilitates understanding of the characteristics of a database. In general , a file is considered to be a basic unit of a set of data and has the following characteristics.

(1) One file corresponds to one unit which can be an accounts book, statistical book, set of maps or a satellite image and its management is of a local character based on the unit.

(2) A file is defined within the framework of the application programme and is stored together with the programme. An example of an application programme is an image processing programme for remote sensing or a programme for a GIS.

(3) Data duplication or correlation between different files is ignored in the system.

The system to store data files produced in separate application fields together with their application programme requires an immense amount of labour and time for file maintenance and updating when the system becomes large. A database is intended to solve this problem in view of its following characteristics.

(1) A database is not a local file serving a specific application field or programme but can be shared by multiple application fields and programmes.

(2) A database compiles a wide range of data required by an organization and conducts the integrated management of these data.

(3) A database has a structure in which changes in the data format or structure can be accommodated by minimum changes in the application programme. This feature is called data independence.

Any system of which the operating system has the above 3 characteristics of a database, i.e. common use of data, integrated management and data independence, is called a database management system or, simply , a database system.

Differences between file processing and database processing from the viewpoint of an application information system are illustrated in Fig. 1-5-1. In the case of file processing, a file which is referred to in an application programme must be defined and the partial definition of a file for processing purposes cannot be accepted. In contrast, only the required part of a file is referred to in database processing. In many cases, data definition is made independently from the application programme. A database provides a function of enabling a free view of data to facilitate the common use of data as well as data independence.

With the increasing demand for databases, there has been an increase in data modelling research to map real world data to computer memories. Efforts are also being made to define data structure and to introduce standard operation specifications for easy data manipulation by users.

1.5.1.2 Remote Sensing System, GIS and Database

The progress of remote sensing data utilization technologies can be divided into 4 stages. Apollo, Skylab and Landsat were launched in the first stage and the satellite images obtained were subject to visual interpretation as in the case of conventional aerial photographs as shown in Fig. 1-5-2 (a). Land use data obtained by the visual interpretation of Landsat images were manually combined with existing maps and tables for management and planning policies.

With the rapid progress of computer technologies, quantitative analysis of satellite data by using digital computer became possible in the late 1970's, paving the way from visual interpretation to automatic analysis (Fig. 1-5-2 (b)). However, the technologies to effectively integrate satellite resources or environmental data with the existing geographic data in a computer programme were still immature in this second stage.

In the early 1980's which marked the third stage of the development of satellite data utilization (Fig. 1-5-2 (c)), image input/output devices and computer graphics technologies made rapid progress and a GIS which could overlay satellite data and existing geographic data in a computer programme was developed. As a result, the spatial overlay of these 2 types of data to conduct a quantitative assessment of resources and resource management planning became possible. Moreover, the progress of computer graphics technologies provided various effective methods of spatial data display.

In the late 1980's, the development of large capacity auxiliary memory devices, especially optical disks, made it possible to store a large volume of spartial data in a single data system. Comprehensive spatial data systems were introduced. In addition to simple overlay analysis, a highly advanced modelling process based on satellite data is now being developed to conduct realistic resources assessment. The integration of resources, environmental and geographic data, including satellite data, in a database now enables the useful combination and analysis of diverse spatial data. Research efforts are also underway to develop a network or an expert system (AI) to facilitate the efficient use of a spatial data system.

Fig. 1-5-2 (d) shows a model of a spatial data system, the objective of which is to analyze and utilize satellite data. For example, rice or wheat harvest forecast data, water resources data and topographical data useful for the evaluation of irrigation potential are integrated in a database together with satellite data. Land cover classification, planting area, vegetation distribution, soil moisture, cloud cover and rainfall analyses can all be based on satellite data. These spatial data are input to an agricultural product harvest forecast model or an irrigation potential assessment model. A data system integrating these spatial data enables accurate and advanced assessment, management and planning. Moreover a fairly complicated assessment model can be made. the sizes of the hardware and software associated with such a spatial data system obviously depends on the application objectives, processing and analysis subjects, volume of data to be handled and the number of users (for a network). The types of satellite data required, analysis method, environmental and resources assessment models, output accuracy, mapping scale, mapping size and spatial resolution are all determined in view of the use purposes of the data. the development of an analysis or evaluation model is also examined form the viewpoint of the same use purposes.

As so far described, the introduction of a data system which integrates, stores and outputs a large volume of diverse data originating from such different sources as satellites, geographic information systems and various statistics is necessary to establish a spatial data system. The conventional file oriented data storage method finds it difficult to meet such requirements as mutual dependence between the master programme and a file is created as explained earlier. Therefore, it is essential to separate the function to process satellite images or geographic data form the data storage function and this can be achieved by a database system.

1.5.2 Basis of Database System

1.5.2.1 4 Types of Human Environments and Their Tasks

A database has such basic characteristics as the common use of data, integrated management and data independence as described in 1.5.1. For the efficient utilization of these characteristics, different capabilities and understanding are required depending on the basic perspective of the system design and utilization. In general, 4 types of human environments are suggested, namely, (1) end user, (2) application programmer, (3) database administrator and (4) organization representative.

A person who uses a ready-made information system (database) at a terminal is called an end user. End-users are generally required to know how to start up and follow the precessing procedure and how to input data (Fig. 1-5-3). It is unnecessary for end-users to understand the database structure or programming procedure in order to have access to a database. In recent database systems, however, the importance of an end-user language associated with data retrieval from a database is strongly suggested. The underlying reason is for a database system to provide end-users with a language which allows simple quoting on the part of end-users so that end-users can handle some of the non-routine processing requirements. Consequently, end-users become capable of conducting simple processing programmes rather than just routine processing, reducing the work burden of the programme specialist called an application programmer.

An application programmer for a database system must know all the programing techniques to refer the database (Fig. 1-5-4). The programmer of a data system must understand the logical structure of the database. The logical structure of a database consists of data items, keys for access to required data and the relation or path to refer to other data.

The logical structure of a database should preferably be in line with the view on the data application programme and should not make end users constantly aware of the path to recall data or the physical structure of the memory device.

A database administrator or data administrator is the person responsible for the management of a database system and fulfills the following functions (Fig. 1-5-5).

(1) manages all data subject to processing by the application system and defines the local structure to create the database

(2) defines the physical structure to reproduce the logical structure of the entire database on a secondly memory device, such as a magnetic disk, in line with the characteristics of both the database system and the hardware

(3) defines the view on data suitable for use purposes or intended application fields

A database administrator must also establish data protection measures at levels (1), (2) and (3) described above to prevent unauthorized reference to and revision of data.

In order to successfully perform these 3 functions, a database administrator must have a proper understanding of the definitions of the generation and preservation of all data required by end-users. In other words, a database administrator is a person who can create a data structure to suit the characteristics of a database system, based on a thorough understanding of user demands for data processing. However, such a thorough understanding is difficult when an application system becomes very extensive. Therefore, in the case of a large application system, it is more practical to divide the functions between more than one database administrator, necessitating the appointment of a senior database administrator who coordinates the decided functions.

Any reference to a database must be made through a database system to maintain the common use of data and integrated management. DD/D (data dictionary/directory) in Fig. 1-5-5 corresponds to the section where the definitions of (1) - (3) are stored and a typical database system using these DD/D data for data reference. In this context, a database administrator is also a DD/D administrator.

A representative of a government agency intending to introduce a database system must correctly recognize the advantages of he integrated management of useful data for the agency and utilize the data in a proper manner. The advantages of introducing a database are considered to be as follows.

(1) common use of data
(2) easy production and alteration of application programmes
(3) integrated management of and reference to data which are generated independently within an organization.

It is now unnecessary to create a new file whenever a new application programme is introduced. The common use of data reduces the redundancy of data by eradicating the need for all application fields to have their own files. The easy production and alternation of application programmes also reduce the necessity to create a new file to the minimum level and data independence shortens the application programme production time. Changes in data do not necessarily require the same amount of changes in application programmes, making the latter more stable. Integrated management enables instant access to resources and environmental data.

1.5.2.2 Data Model

1.5.2.2.1 Outline of Data Structure

The most fundamental issue when discussing a database is how to structure real world data in a physical expression which can be understood by a computer. In other words, the issue is how to construct a data model.

A database presupposes the common use of data by multiple application programmes. Consequently, a degree of freedom which allow s different views of a data set depending on application programmes is required instead of the fixed structure associated with conventional definition.

1.5.2.2.2 Three-Layered Data Modelling

The three-layered interface between application programmes and a database shown in Fig. 1-5-5 is the basis for database modelling. By rearranging the interfaces in a database system, the three-layered data model in Fig. 1-5-6 is obtained.

As a conceptual model defines the entire real world data required for data processing, its definition does not depend on a specific view of an application programme or the characteristics of the computer system. Such a conceptual model is equivalent to the logical structure in Fig.1-5-5.

An external mode defines the user's view of data shown in Fig. 1-5-5 and is part of the database seen from the viewpoint of an application programme. As such, it can be regraded as a partial set of a defined data structure of a conceptual model. The language describing the external model is determined, by the programming language in which the application programme is written.

An internal model is the view of the computer of the data and defines the physical structure in Fig. 1-5-5. Such definition shows how a database defined by a conceptual model is reproduced on a computer.

The concrete definitions of a conceptual model, external model and internal model are called a conceptual schema, external schema and internal schema respectively. A real database does not necessarily define itself in terms of these three-layered schemata. Nevertheless, the introduction of the 3 schemata, i.e. conceptual schema, external schema and internal schema, to respectively represent the real world's view of data, user's view of data and computer's view of data has practical convenience. A medium control function may be added in an actual system to represent a more physical level than an internal schema. In some cases, lower functions than an internal schema are included in the operating system.

A conceptual schema, external schema and internal schema are defined by descriptive languages. Descriptions of data, such as data attributes, names and protection data, are called meta-data. Meta-data based on the definition of each schema are controlled by the DD/D (data dictionary/directory) which consists of a data dictionary to control definition data for users and a data directory to control definition data for software programmes. Recent database systems tend to emphasize the data dictionary to control a large volume of data and many attributes. Similarly, recent data dictionaries increasingly incorporate such information as semantic restrictions on data and the attachment of a distributed database in addition to more conventional information on data names, attributes and mutual relationships.

1.5.2.2.3 Data Model

A database system must transform real world data to computer data for processing by an information system. The tree model used in graph theory or an information structure are generally referred to in order to examine a possible data model. A tree consists of nodes and branches as shown in Fig. 1-5-7. A node of a database tree is considered to be a basic processing unit of a database system. There are several ideas on how to deal with branches connecting nodes and the classification of data models is based on different ideas. The following 3 data models are best known.

(1) hierarchical model
(2) network model
(3) relational model

A hierarchical model provides such structure as the most similar one of a natural tree, and is called hence tree structure. Branches are expanding from nodes regarded as roots of trees.

A network model allows higher degree of independence on tree structure than a hierarchical model, and is the most representative model on the whole.

A relational model intends the expression of data only by nodes. A unit corresponding to a record is called a tuple and the record type is shown by a table. As the relational model lacks the definition of data to define the structure and as it allows data separate and integration based on attributes, it has a high degree of data independence as well as a high freedom of user's view. As a result, it is the data model which is best endowed with the inherent characteristics of a database.

1.5.2.3 Database Mechanism

It is useful to understand the general mechanism of a database to understand the basic issues involved in the introduction and operation of a database.

1.5.2.3.1 Data Preparation

The starting point for the introduction of a database is to put information into suitable data form. Information here means facts of the real world, such as demographic tables, crop harvests, crop planting areas, map data and satellite images, etc., while data means the reproduced information on a storage medium, such as a magnetic disk. The starting point of a database system is, therefore, the data modelling described earlier.

The basic types of work which are important in data modelling are as follows.

(1) collection of useful real world information
(2) integration of information into a convenient logical structure while removing duplications and redundancies as much as possible
(3) optimal modelling of the data structure

The collection of real world data must be extensive. While it is not particularly difficult to collect data relating to routine work, useful data may not be collected in the case of an extensive field subject to data collection. If the work has already progressed to stage (2) or (3) when an omission of useful data is discovered, the work must restart from stage (1). Such a possibility demands that a database administrator and programmer must have thorough knowledge of the application purposes and related real world.

Stage (2) becomes increasingly more difficult with the greater the size of an application system. The basic posture for stage (3) is to achieve an efficient projection of the data structure decided in Stage (2) to the computer system. More important is to make database functions which allow the efficient and swift retrieval of the required data using an application programme. It must be noted that the creation of a database by stages (1) - (3) has the inherent objective of processing multiple data to different sets of data in addition to the basic objective of obtaining the required data with little difficulty.

A proper understanding of the expected effects of an information system which is created through work stages (1) - (3) is essential to smoothly conduct such work so as to prevent subsequent operational problems. The introduction of a database to an information system is generally expected to have the following effects.

(1) increased flexibility of the information system due to the common use of data
(2) stabilization of the information system
(3) improved reliability of the information system

In designing data, the basic effects of a database described above must be assessed in concrete terms and targets and methods must be clearly decided vis-a vis the following items.

(1) data standardization
(2) confirmation of data legitimacy
(3) assessment of performance, such as throughput
(4) preservation of data safety
(5) recovery
(6) required security measures
(7) exchange of data with external organizations

Fig. 1-5-8 gives an outline of an information system to which a database is introduced. In the case of a database system, a subsystem implementing data manipulation based on an information system programme often differs from a subsystem which defines data because of data independence. A data definition subsystem determines and alters the definitions of the conceptual schema and external schema explained in 1.5.2.2.2 based on the data modelling results. The generation of a database based on data definitions given by a data definition subsystem is usually conducted using a special utility programme. A set of commands for data definition is called a data description language (DDL). The reorganization of data following changes in data definition also tends to be conducted using a special utility programme. A database administrator is responsible for conducting these types of work in addition to the definition of data and the generation/reorganization of a database using a special utility programme.

1.5.2.3.2 Data Manipulation

The most important requirement for an application programmer is a thorough understanding of the data manipulation subsystem and related functions shown in Fig.1-5-8. This relates to a basic knowledge of the manipulation of data stored in a database using an application programme. To manipulate data stored in a database using an existing programming language, such as FORTRAN or C, based on data model information defined by a conceptual schema and external schema, the use of data manipulation commands which differ from the data input and output commands is common. A set of these manipulation commands is called a data manipulation language (DML). A data manipulation language is not an independent programming language for data processing but is simply a set of extended commands of an existing programming language.

A system which enables data manipulation using extended commands of an existing programming language is called a host language system. In comparison, a system which is equipped with a built-in data manipulation function vis-a vis a database is called a self-contained system. Although a host language is commonly used, the self-contained system is popular for a simple database reference system for end users. When a DML or user language commands are added to an existing programming language in a host language system, the newly written programme cannot be directly fed to the existing programming language compiler. Consequently, the compiler must be altered or a precompiling function to convert a DML to an existing programming language must be introduced. In an actual commercial database system, a data manipulation language is given as an integrated subroutine, such as the CALL command of FORTRAN. Even if a pre-compiling function is provided, a command by a DML is often converted to the CALL command to create a new source programme.

The relationship between an application programme involving image processing or geographic information processing and a database system must be examined from the viewpoint of the operating system in terms of job management or task management. The different views on data manipulation are classified as shown in Fig. 1-5-9. The unit surrounded by a dotted line corresponds to a job, i.e. an operation unit for an operating system. In Example A, the required parts of the database system are separately integrated to the relevant application systems. The application programmes and database conduct different jobs in Example B. This style is adopted for many relatively large commercial database systems. In this case, the database system must be capable of multiple task management to concurrently accept data manipulation demands by multiple application programmes. In Example 3, this multiple task management is assigned to the application programme level. In this system, multiple database systems can be managed by a single operating system.

1.5.2.4 Relational Database

A database using a relational model is called a relational database. A relational model is the Application of the mathematical concept of relation to data manipulation. Relation is a general concept which does not only express substances in the real world but also relations between substances. The objectives of a relational database are given below.

(1) achievement of high data independence
(2) provision of a simple view of data which can be commonly used by computer experts and non-experts alike
(3) mitigation of burden of a database administrator
(4) establishment of a theoretical basis for a database system
(5) integration of AI to file management for future application
(6) upgrading of application programmes of a database from the level of a procedure oriented language to a non-procedure oriented language which addresses a set.

These objectives of a relational model can be achieved by the following 3 principles.

(1) independence of an application programme from the physical locations of and restrictions on data

(2) independence of an application programme from measures to improve its performance, such as an index and an inverted file

(3) independence of an application programme from a calling sequence

In the case of conventional file processing, changes in the order of records in a file or physical attributes to these records necessitate changes in the application programme. To prevent such changes, data should be expressed independently from the physical properties of the computer system and an application programme should be made bearing this requirement in mind.

When an end-user creates an application programme which integrates measures to upgrade the programme performance by means of an index or inverted file, the application programme must follow changes in the environmental conditions of the application system, shortening its life. The independence of an application programme from performance upgrading measures is designed to prevent this.

With regard to (3), an application programmer must design a logical data structure, taking the data calling sequence into full consideration, in the case of a set type or a layered data model. Since real world data undergo dynamic changes, an application programme which is dependent on the calling sequence becomes unstable in the attempt to accommodate such changes. Therefore, it is preferable that an application programme be independent form a calling sequence. Fig. 1-5-10 gives examples of relational tables.

The correspondence of the terms used in a relational model with conventional data processing terms is given below for a better understanding of the concept of a relational model.

Terms of Relational Model	Terms of Conventional Data Processing
relation, relational table	file
tuple	record
attribute	data item, variable number
relational schema	record format

It must be noted that relation is not an exact synonym for file.

1.5.2.5 Distributed Database System

A change in computer use from centralized processing by a main frame to horizontal distributed processing by multiple processors occurred in the 1980's due to the advantages of the latter in terms of risk distribution and easy application. The rapid progress of work-station technologies and the wide spread of data communication in recent years have created a favourable environment for distributed processing. The development of distributed processing has in turn facilitated the direct operation of computers by end users instead of computer experts stationed in a computer room.

In the case of a distributed database system, the database is distributed to and managed by multiple processors (work stations). In this sense, a distributed database is one form of distributed processing. While many models are possible for a distributed database system, the usual system is that a common database for various application systems is distributed to multiple work stations which are connected by a data communication channel, such as a LAN. Database distribution is skillfully conducts so that the end user does not have to be aware of to which work station the required data are distributed.

A Distributed database system has the following advantages.

(1) improved system reliability
(2) flexible system development and upgrading
It also has the following disadvantages.

(1) complicated operation system control to retrieve data as control of the communication network is necessary.
(2) more complicated system operation than the centralized type

A horizontal distributed database system still requires technological refinements in regard to the uneven quality of schemata, reliable and prompt connection between processors and the simultaneous access to and control of a database by multiple end-users. When the number of work stations connected to a single horizontal distributed database exceeds 20, database management becomes very complex. Therefore, the introduction of a vertical, as well as a horizontal, distributed database using a main frame (mini supercomputer) along-with the work stations should be considered for a large scale database.

1.5.3 Remote Sensing Data

As described in 1.5.1.2, there is a large demand for a system which is capable of integrating, storing and processing diverse data, such as satellite images, geographic information, attribute data and statistical data, etc., for various application purposes. Conventional file oriented data storage and processing finds it difficult to meet this demand as it presupposes mutual dependence between a programme and a file. Therefore, the processing of satellite images and geographic information should be separated from the data storage function.

While there are many softwares for remote sensing and GIS application, they do not normally contain a database management system. As a result, the capacity to integrate wide area data is small. The lack of a data protection function poses another problem.

In contrast, the currently marketed database management systems aim at providing telephone numbers and addresses or the transfer of money from one account to another. While the data storage capacity of these databases is fairly large, only a small volume of data can be simultaneously accessed for application processing purposes. A GIS must provide single access to between a few kilobytes and several megabytes while a remote sensing system must provide single access to between a few megabytes and several hundred megabytes. In the simultaneous processing and display of such a large volume of data, slow access and slow data transfer are critical. A long access time in remote sensing system or a GIS means difficulties in conventional processing. The creation of a data system, which enables end users to refer to maps or images at an adequate speed to maintain an interactive mode is necessary.

A remote sensing database also differs from an ordinary database in that it requires a seamless database. Maps and images are classified into sheets and each map sheet is regarded as one handling unit. However, it is inconvenient if the fully display of the subject area for analysis cannot be obtained because of map or image boundaries. Consequently, a seamless database which enables end-users to freely move maps or images and to conduct zooming, such as enlargement and reduction, is required.

1.5.3.1 GIS and Database

The volume of GIS data which can be efficiently accessed and processed for single display on a CRT is believed to be some 2,000 - 5,000 points, line and symbols. In conventional processing, a response time of more than 30 seconds is said to disturb end-users concentration. As one map is believed to have some 1 megabyte of data the marketed database systems are unable to provide prompt. simultaneous access. One solution to this problem is the creation of a layered structure where a set of software modules performing a certain function is considered to form a layer (Fig. 1-5-11).

The bottom layer (Layer 1) relates to the improvement of data access and is direct connected to the function of the operating system for access to the file system. It also stores and refers to data using internal record identifiers.

Layer 2 protects the data and its operation is basically the same as in the case of Layer 1. It ensures that changes in the database do not cause losses to other end-users and provides a security lock function. Layer 3 ensured access to such numerical data as addresses based in such geographic coordinates as latitude and longitude. Layer 4 relates to services for GIS users and provides logical tools for data access and data manipulation based on logical schema.

A GIS database also differs from an ordinary database in that such elements as points, line and symbols are given such spatial relationships with other as "near" and "neibouring", etc. A paddy field along National Route 16 or river flowing into the Tone River indicate such spatial relationships. Therefore, it is important to ensure efficient access to all related elements.

1.5.3.2 Integration of Remote Sensing, GIS and Database

The analysis of remote sensing data deals with many more data files than a GIS. The volume of TM data to cover one scene (some $180km^2$) is approximately 250 megabytes. It is difficult to create a practical database system which stores such an enormous volume of data and provides free access to all data at a conversational speed. The integration of remote sensing to a GIS has been in progress in recent years to facilitate the efficient use of remote sensing data (Fig. 1-5-2 (d)).

The main objectives of such an integrated system are the same as those for any other ordinary database system and are given below.

(1) curtailment of data duplication and inconsistencies (common use of data)
(2) accumulation of diverse data for efficient use (integrated management of data)
(3) easy and efficient alteration of application programmes and data (data independence)

(4) acquisition of a new set of data which cannot be directly given from an original set of data (GIS)

Remote sensing data are raster data (images) while an ordinary GIS mainly uses vector data obtained by digitizing maps and from other sources. For a remote sensing database, it is of crucial importance to produce a data interface which efficiently integrates the 2 types of spatial data, i.e. vector data (maps) and raster data (images). In addition, an interface between spatial data and aspatial data, such as attribute data, is required.

For a system which centers on the analysis and use of satellite data, a GIS using raster data is more compatible with satellite data in view of easy processing. Not only simple overlay analysis but also both analysis and assessment using advanced modelling are made easier. output of the analysis results can be conducted in either raster form or vector form. A likely integrated system will, therefore, consist of an ordinary relational database management system (RDBMS) and a spatial modelling system (GIS) using raster data while also having strong cooperation with a vector type GIS. Fig. 1-5-12 gives an example of such an integrated system which has 3 key software components. It also has subsystem corresponding to such functions as (1) data input, output and display, (2) database management and (3) data computation.

Fig. 1-5-13 shows the relationship between the spatial components and aspatial components in a remote sensing and GIS integrated system. The analysis results of satellite raster data and geographic data are given numerically indexed region codes for each point or area and these codes are used as keys for the corresponding spatial data. Related attributes are stored in a relational table as tuples. More advanced database use becomes possible with the creation of multiple relational tables for a single layer of a GIS, such as vegetation. A database on ground truth or a training area for land use analysis can be made in the form of a relational table. In this way, the computation of spatial data can be replaced by the much simpler relational computation. New attributes obtained by relational computation can be further used for the next spatial computation (vector form) or display.

Reference to spatial data can be made by 2 methods. The first method uses a raster based information system which defines the subject area by geographic coordinates and refers to related data in the area from an aspatial database. It is also an idea to register reference maps (index maps) on a small scale to the system so that a required map can be obtained after several stages of downward search from a larger scale map.

The second method uses such attributes as area names, city names and cultivated fields for specific crops, etc. With the application of special data manipulation (relational computation), such as relational logic or relational algebra, reference with complicated conditions is made possible. The image data of the subject data can be retrieved from a raster type image database using spatial indices on relational tables, selected by relational computation.

A typical analysis procedure using such a system is a follows.

(1) digitization correction and editing of geographic information by a vector type spatial data system (a GIS)
(2) conversion of vector data to satellite data for overlay with satellite data to facilitate model analysis, assessment and simulation
(3) output in the form of hybrid graphics if necessary

Fig. 1-5-14 shows the development flow of such a database. It must be noted that proper consideration must be given to such aspects as human training, the use value of hardware, technological trend of computer systems and cost performance etc. in the design of a database.

1.5.4 Data Processing Environment

1.5.4.1 Trends

A major change is taking place in the computer industry (Fig. 1-5-15). The rapid advancement of micro processing units (MPU) has resulted in revolutionary improvements in the performance of such small computers as personal computers and work stations. In contrast, the demand for medium size computers and main frames is declining to the extend that even their eventual extinction is being discussed. 32 bit, MPUs, the wide use of which commenced in 1987, have proven very effective and the performance of a personal computer with a 32 bit MPU equals that of a small main frame in the 1970's. Traditionally, a main frame is the size of an automobile, requiring a special power source and special air-conditioning, etc. and locational in specially designed room. Main frames (Fig. 1-5-16 ①) have a long history in use and have super file management and back-up functions. They also have such advantages as the simultaneous running of multiple programmes and the simultaneous handling of many end-users (multi task function). In comparison, workstations are small enough to be installed at the side of a desk and require neither special air-conditioning nor a special power source. Many softwares providing a network environment (distributed processing), a multi-window function and graphical user interface (GUI), etc. are currently on the market, making the use of a workstation easy for all. There are many softwares with an excellent data collection speed and/or graphics application. The cost performance is more than 10 times better than that of a main frame due to the use of reduced instruction set computing (RISC) architecture to improve the chip quality and clock speed. The improved processing speed achieved by the application of optimal compiler technology has also contributed to the excellent cost performance of work stations.

The development of database systems has been stimulated by the desire to make a large information system using large files easy to maintain and update. As a result, main frames were that main actors in the use of databases up until the late 1970's. In the 1980's, however, the rapid progress of the computer environment generated a strong demand for database utilization in the field of such small computers as workstations and personal computers. Moreover, database are increasingly becoming a basic component of any computer system rather than being a special feature for particular applications. The inclusion of a database function in FORTRAN 77 is a case in point. A fourth generation programming language will contains a database function as a special feature of its development.

More recently, the number of systems where workstations are used as servers of a database in a network in increasing. The character of a database is changing from the single large collection of data to distributed data for common sharing. The technological progress in sharing data and files, etc. in a distributed processing and distributed data environment is behind this change.

1.5.4.2 Open Type Distributed Processing System

A distributed processing environment (Fig. 1-5-16②)has developed with the super mini computer system incorporating a network (LAN). This system is capable of performing the same job at one-third of the cost of a centralized processing system using a general purpose host computer. However, a LAN has a critical shortcoming in that t it always requires file transfer whenever the use of a file or data of another work station is intended. As a result, a LAN requires a lot of time for file transfer. The duplicated storage of files and the subsequent piling up of files of different versions inside the network pose additional problems. An open type distributed processing system has been developed to solve the problems, (Fig. 1-5-16③). A horizontal distributed processing system, combining a LAN and a distributed file system, enables end users to treat any file in the network (LAN) as their own file. End users can also open a window on the work station of someone else and assign jobs to it. This open type distributed processing system can do the same or even better work than a centralized processing system at one-tenth of the cost of the latter.

The difference between a personal computer and a work station lies in the latter's connection to a network. When a personal computer is connected to a network, it becomes a workstation (and also a terminal window). With this newly acquired connection, the use of a personal computer changes its character from standing alone to network participation (or a peripheral data processing node within a large system).

The transfer and exchange of files pertaining to geographic information (vector data), images (raster data) and statistical values become possible by connecting a personal computer to a network (LAN: ETHERNER). It is now possible to enjoy an inexpensive personal computer, the performance of which equals that of a workstation, with a 32 bit processor, a hard disk of over 300 MB and a high resolution image board. The use of a personal computer system to run a database enables distributed processing. The personal computer of today is capable of map input by a digitizer and its correction, which requires long input and conversational processing, making use of a host computer more efficient. For reference, the input of a map by a digitizer usually requires one week to complete.

There are some disadvantages in the use of a personal computer system. The use of MS-DOS does not allow reference to a distributed file system and restricts the size of a file to be processed. Nevertheless, a personal computer has sufficient capability and efficiency to handled data input and output.

1.5.4.3 User Interface

With the increasing use of computers, particular attention is being paid to a man-machine interface or a user interface which deals with the field where the computer and its user meet. People with no technical knowledge of computers can enjoy playing computer games or can operate a Mackintosh because of an excellent user interface. The increasing number of people using computers has improved such user interfaces. An easy to use software is said to allocate 30 - 40% of its source codes to the user interface. An improved user interface makes a software easy to use and improves its reputation.

A command system and menu system are well-known systems to execute a programme. The recent advancement of a bit map display and various pointing devices has made many softwares adopt a graphics display for a user interface while the basic objectives of such a graphics display are the same as those of a menu system, the use of graphics makes it easier for a user to proceed. A further development of the menu system is the pull-down menu system where the selection of a menu automatically leads to the display of a sub-menu and sub-sub-menu. This system is called a pull-down menu system as different menus are displayed like a hanging screen.

The window system is widely used in the case of a workstation. A window system using a graphical user interface (GUI) has been developed to make the computer manipulation environment resemble human ways of doing things. The hyper card system is known as an environment which allows application development with minimum restrictions. It involves the indexing of texts, images and sound into cards with the same format and creates and environment in which these cards can be freely refereed to and used.

Recent input devices include a bit map display, keyboard, mouse, touch screen, touch pen and bar code reader, etc. A user interface for a digitizer is also being improved for the efficient input of coordinates.

1.5.4.4 Data Processing Environment in Phase II

The introduction of the integrated remote sensing and GIS system described in 1.5.3 is anticipated in Phase II.

(1) System Conditions

The basic types sand volumes of the input data to be handled by the Center are shown in Table 1-5-1. The initial amount of data is estimated to be some 7 gigabytes. In reality, as the system cannot be developed by PU staff alone, even in 5 years' time, it will be necessary to share other related map databases. The main users of the new system will be staff members of the PU (approximately 11) and Japanese experts. The system to be introduced should satisfy such conditions as ① easy maintenance without reliance on a computer engineer, ② low power consumption and the safeguarding of operation against power cuts or sudden voltage reductions by means of an auxiliary power source and ③ complete manuals of the system in English.

(2) System

The conditions described in (1) above suggest the adoption of a horizontal distributed computing environment using light weight and easy to maintain workstations and personal computers connected to a network (LAN) rather that a centralized processing environment using a single main frame.

In short, the new system for Phase II will be characterized by the following.

1) continuous use of Phase I equipment to analyze satellite data
2) creation of a database with an open type horizontal distributed processing environment using work stations and personal computers.

2 work stations will be installed to handle a raster type database and a vector type database. A server type large work station will suit the vector type database in view of the large volume of data to be processed. A software with a turnkey system will be used to reduce the programme development burden. Since a database function alone is insufficient to analyze geographic data to assist central government agencies and local governments in the formulation of better policies, a data analysis function is essential. An additional work station will, therefore, be installed to conduct RDBMS, data analysis and modelling. These 3 work stations should be the same model to facilitate their networking and easy maintenance. The breakdown of one work station will be temporarily compensated for by the other 2 units.

As input using a digitizer is a time consuming process, a GIS system run by a digitizer incorporated personal computer system will be introduced for database input. Assuming that the input operation of a map requires one week, 200 maps will require 200 weeks (4 years), necessitating the introduction of 2 or more sets of personal computer systems for data input. Moreover, the inclusion of an off-line auto scanner is desirable to further improve the data input efficiency. The provision of a raster type database (GIS) is hoped for to serve personal computer systems in local areas. At least one set of the same personal computer system should be connected to the network at the Center to exchange data with local systems and for the training of local staff.

A 5 inch rewritable optical-magnetic disk with a data storage capacity is some 600MB and a cartridge tape device with a data storage capacity of some 2 GB will be connected to a backup file server (workstation) to provide backup for the database.

Data exchange between the Phase I system and the Phase II system will be made by magnetic tapes or LAN.

(3) Local System

The introduction of a vector type GIS as a local system and the sharing of the input of map information (vector data) by the local system is desired. To respond to this desire, a digitizer will be connected to the local system to enable map input operation. Data will be exchanged with the Center in the form of floppy disks.

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