

INVESTIGATION OF THE EFFECTIVENESS AND APPLICATIONS OF JAPANESE ERS-1 STEREOSCOPIC IMAGES.

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Abstract

A remote sensing satellite named Japanese Earth Resources Satellite-1 (JERS-1) is scheduled to be launched in 1992 in Japan. The satellite will be able to take stereoscopic images continuously by two linear array sensors. In this work, we developed a system to make JERS-1 simulation stereoscopic images by computer, and then using this system, we produced stereoscopic images from a Large Format Camera (LFC) photograph taken from the space shuttle. We investigated the quality and the usefulness of the JERS-1 stereoscopic images using these simulation images. The result of this work is that we can get high quality stereoscopic vision to explore earth resources from JERS-1 stereoscopic images which have about 20 m ground resolution and 0.3 base-to-height ratio.

1. Introduction

Recently stereoscopic images taken from satellites are drawing the attention of the world. SPOT-1, which was launched in 1986, was essentially the first satellite to have the function of stereoscopic viewing and many investigations about SPOT stereoscopic images are being executed now. Japan is planning to launch another stereoscopic viewing satellite, JERS-1, in 1992. The main difference between SPOT-1 and JERS-1 is that SPOT-1 takes stereoscopic images in two different orbits using a side-looking image sensor but JERS-1 takes them in the same orbit using nadir and forward looking image sensors. This difference in the image-taking method causes some differences in image features. So it is necessary to investigate the feature of JERS-1 stereoscopic images in detail.

The projection method of satellite images is different from photographic images, the satellite image is a cylindrical projection but the photographic is a central projection. Therefore, there are many new problems to be resolved in satellite stereoscopic images. It is the main purpose of this work to make simulation stereoscopic images to investigate the features and the quality of JERS-1 stereoscopic images. Another purpose of this work is to evaluate some parameters of JERS-1 stereoscopic viewing to confirm the adequacy of the design. The third purpose of this work is to investigate the usefulness of JERS-1 stereoscopic images to develop their application fields.

2. Japanese earth resources satellite-1 (JERS-1)

JERS-1 is a remote sensing satellite designed to gather image data which are useful to explore earth resources. It will be launched in 1992 in Japan. Its weight is 1.4 tons and the altitude of its orbit will be 568 km.

JERS-1 has two kinds of imaging systems. One is synthetic aperture radar (SAR) and the other is optical sensor. The wavelength of SAR is L band and the resolution of SAR image is 18 m. The swath width of both sensors is 75 km. The ground resolution of optical sensor is 18.3 m x 24.0 m for the nadir looking sensor and about 19.1 m x 24.0 m for the forward looking sensor. The nadir looking sensor takes seven band images in the wavelengths of visible, near infrared and shortwave infrared. The forward looking sensor takes one band image in shortwave infrared wavelength.

The combination of a nadir looking sensor image and a forward looking sensor image produces stereoscopic vision. The base-to-height ratio of JERS-1 stereoscopic images is fixed to 0.3. This ratio can not be enlarged because the nadir looking sensor and the forward looking sensor must be placed in the same telescope due to considerations of weight limitations etc.

3. Development of a system to make JERS-1 simulation stereoscopic images.

We developed a system to make JERS-1 simulation stereoscopic images from photographs by computer. The quality and usefulness of JERS-1 stereoscopic images can be investigated using the output of this system. Figure 1 shows the general flow of this system. The details of the components of this figure will be explained next.

LFC photo. (Large Format Camera photo.)

The input image data of this system is photographic, particularly by LFC photograph taken from the space shuttle. LFC photograph is very suitable for this system because it covers a very large area with high ground resolution (about 15 ~ 20 m) similar to JERS-1 stereoscopic images. Moreover a photograph has another merit in that the image distortion of a photograph can be corrected more exactly than that of a satellite image.

Digital image

The input LFC photograph is converted to a digital image by drum-scanner.

Exterior orientation parameters

The exterior orientation parameters are extracted from a positive-film of the LFC photograph using the aerotriangulation method.

Map

Maps with contours are used to make a digital terrain model (DTM). In this work we used maps of 1:50,000 scale. The contours of the map are converted to a digital image by drum-scanner.

DTM

DTM with 18.3 m interval is made from the digital image of contours using computer. But the height information of each contour must be attached line by line manually.

Orthophoto image

A digital image of a photograph is converted to an orthophoto image using DTM and exterior orientation parameters. In this conversion the earth curvature is taken into account.

Parameters of JERS-1

Some parameters of JERS-1, such as ground resolution, base-to-height ratio and the angle of the forward looking sensor are used to make JERS-1 simulation stereoscopic images.

JERS-1 stereoscopic images

An orthophoto image is converted to JERS-1 stereoscopic images using DTM and parameters of JERS-1. The base-to-height ratio of JERS-1 stereoscopic images is fixed to 0.3, but in this system we can select any other base-to-height ratio of stereoscopic images. The details of this part will be explained in the next section.

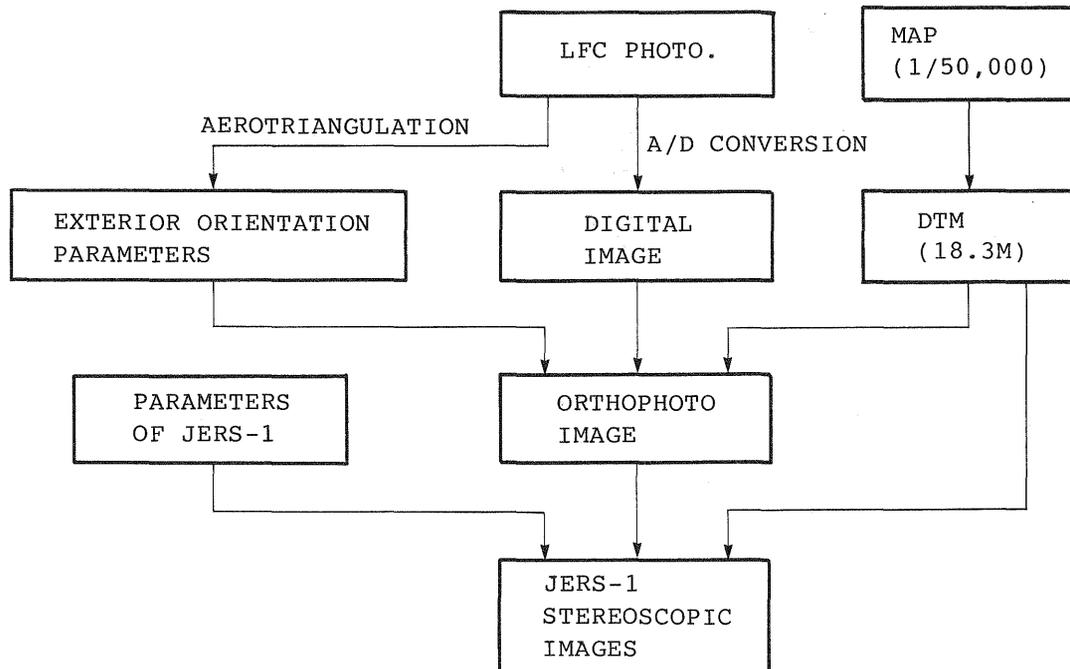


Figure 1 General flow of the system to make JERS-1 simulation stereoscopic images

4. Mathematical method to make JERS-1 simulation stereoscopic images

JERS-1 simulation images are made point by point determining the earth's surface points sensed by sensor elements in a linear array sensor at any time. We will explain the way to determine the sensed point by a sensor element in this section.

Figure 2 shows the relationship between the ground co-ordinates (X, Y, Z) and the satellite co-ordinates (X_{st}, Y_{st}, Z_{st}) . Both sets of co-ordinates are rectangular plane co-ordinates and are defined on the earth's surface and on the satellite respectively.

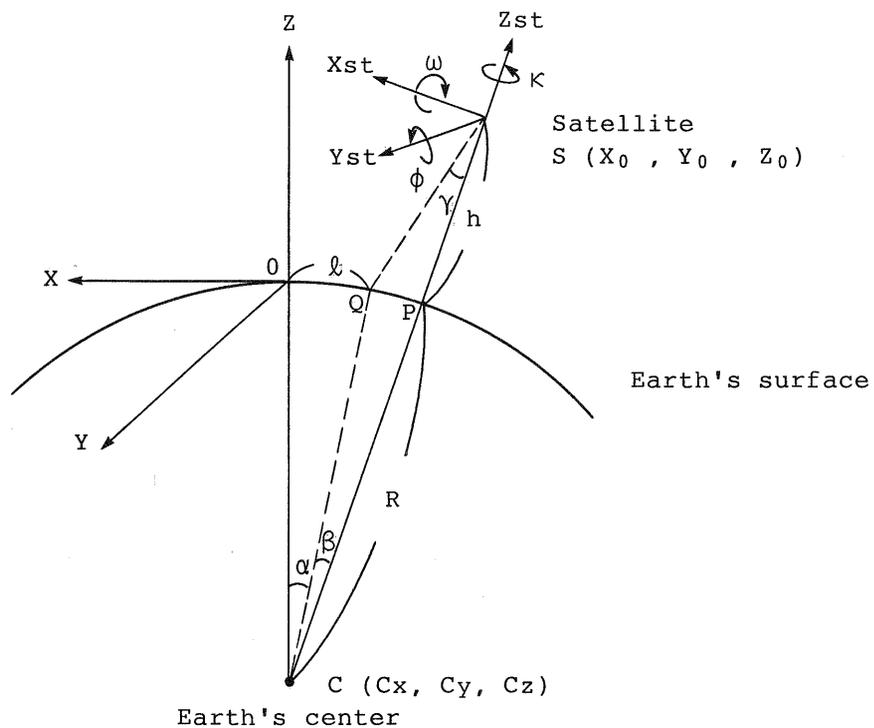


Figure 2 Relationship between the ground co-ordinates (X, Y, Z) and the satellite co-ordinates (X_{st}, Y_{st}, Z_{st})

The X-Z plane and the Xst-Zst plane are the same and the satellite flies on the plane towards the Xst axis direction. R is the earth's radius. h is the satellite altitude. Point C (Cx, Cy, Cz) is the earth's center in the ground co-ordinates. Point P on the earth's surface is directly below the satellite and the nadir looking sensor faces here. Point Q on the earth's surface is where the forward looking sensor is directed. Angle γ can be determined from the base-to-height ratio of this stereoscopic imaging system. Angle β can be determined from the angle γ . Length l is the length along the earth's surface between the origin O and the point Q. Angle α can be determined from the length l. The satellite always faces the earth because the satellite rotates once when it flies around the earth. From these conditions mentioned above, the satellite position S (X₀, Y₀, Z₀) in the ground co-ordinates and the satellite attitude, that is, the rotation angle ω , ϕ , κ around the axes X, Y, Z, can be expressed as follows.

Satellite position

$$\begin{aligned} X_0 &= Cx + (R + h) \cos \left(\frac{\pi}{2} + \alpha + \beta \right) \dots\dots\dots (1) \\ Y_0 &= Cy \dots\dots\dots (2) \\ Z_0 &= Cz + (R + h) \sin \left(\frac{\pi}{2} + \alpha + \beta \right) \dots\dots\dots (3) \end{aligned}$$

Satellite Attitude

$$\begin{aligned} \omega &= \kappa = 0 \dots\dots\dots (4) \\ \phi &= -(\alpha + \beta) \dots\dots\dots (5) \end{aligned}$$

The co-ordinates transformation equation between ground co-ordinates (X, Y, Z) and satellite co-ordinates (Xst, Yst, Zst) can be expressed as follows.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \cdot \begin{bmatrix} Xst \\ Yst \\ Zst \end{bmatrix} + \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} \dots\dots\dots (6)$$

$$\begin{aligned} a_{11} &= \cos\kappa \cdot \cos\phi \\ a_{21} &= \sin\kappa \cdot \cos\phi \cdot \cos\omega + \sin\omega \cdot \sin\phi \\ a_{31} &= \sin\omega \cdot \sin\kappa \cdot \cos\phi - \sin\phi \cdot \cos\omega \\ a_{12} &= -\sin\kappa \\ a_{22} &= \cos\omega \cdot \cos\kappa \\ a_{32} &= \cos\kappa \cdot \sin\omega \\ a_{13} &= \cos\kappa \cdot \sin\phi \\ a_{23} &= \cos\omega \cdot \sin\kappa \cdot \sin\phi - \sin\omega \cdot \cos\phi \\ a_{33} &= \sin\omega \cdot \sin\kappa \cdot \sin\phi + \cos\omega \cdot \cos\phi \end{aligned}$$

Using this transformation equation we can express the position of the linear array sensor and the center of projection in the ground co-ordinates.

Figure 3 shows the method to determine the earth's surface point sensed by a sensor element in a linear array sensor. Point I is the center of projection. Point J is a position of sensor element in the linear array sensor. There are about 4,000 sensor elements in the linear array sensor. The position K sensed by the sensor element J can be determined as the cross point of the line I-J and the DTM, that is, the earth's surface. The line I-J shows the beam of light from the point K on the earth's surface to the sensor element J. This point K can be calculated using the successive approximation method as follows.

At first the height of the point K is hypothesized as a certain value and the cross point with the line I-J, M, is calculated. Then the true earth's surface at the position M, here the point N, is calculated and the second height of the point K is hypothesized between the points M and N. We can determine the approximate height of the point K by repeating this process.

The point sensed by a sensor element at any time can be determined like this and the brightness of that point can be determined from the orthophoto image made from the LFC photograph. A JERS-1 simulation image can be made by determining the brightness of all the picture elements point by point like this.

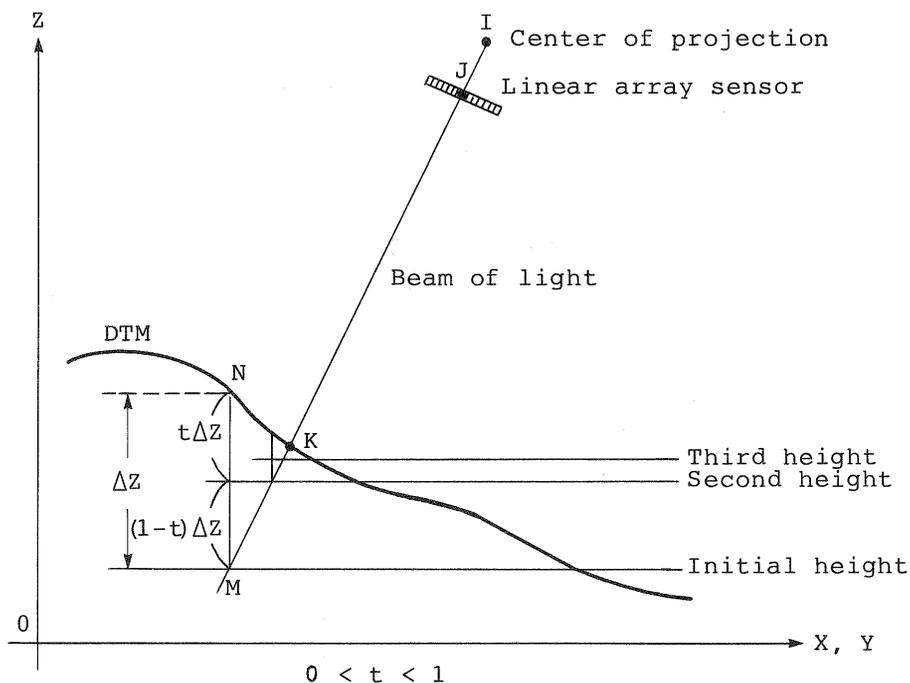


Figure 3 Method to determine the earth's surface point sensed by a sensor element in a linear array sensor

5. Production and evaluation of JERS-1 simulation stereoscopic images

We produced some JERS-1 simulation stereoscopic images using this system. As an input image we used an LFC photograph of the Izu peninsula in Japan taken from the space shuttle. Photo 1 is the photograph but only the left side is printed.

Photo 2 is one output of our system which simulates the JERS-1 nadir looking sensor image. Photo 3 is another output which simulates the JERS-1 forward looking sensor image. These two images produce a stereoscopic vision of 0.3 base-to-height ratio. We derived some significant results from the evaluation of these stereoscopic images.

One of them is that the base-to-height ratio of JERS-1, 0.3, is a little small, but we can get an acceptable vertical exaggeration to see the shape of the earth's surface. Another result is that the ground resolution, about 20 m, is more than adequate to extract the terrain features of the earth's surface.

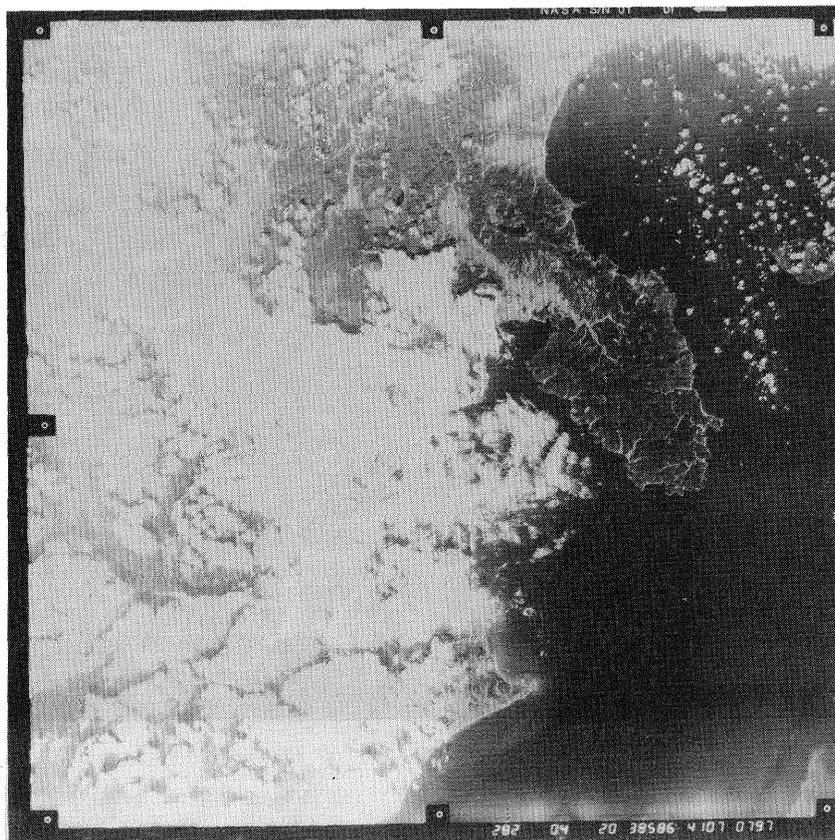


Photo 1 LFC photograph of the Izu peninsula in Japan taken from the space shuttle

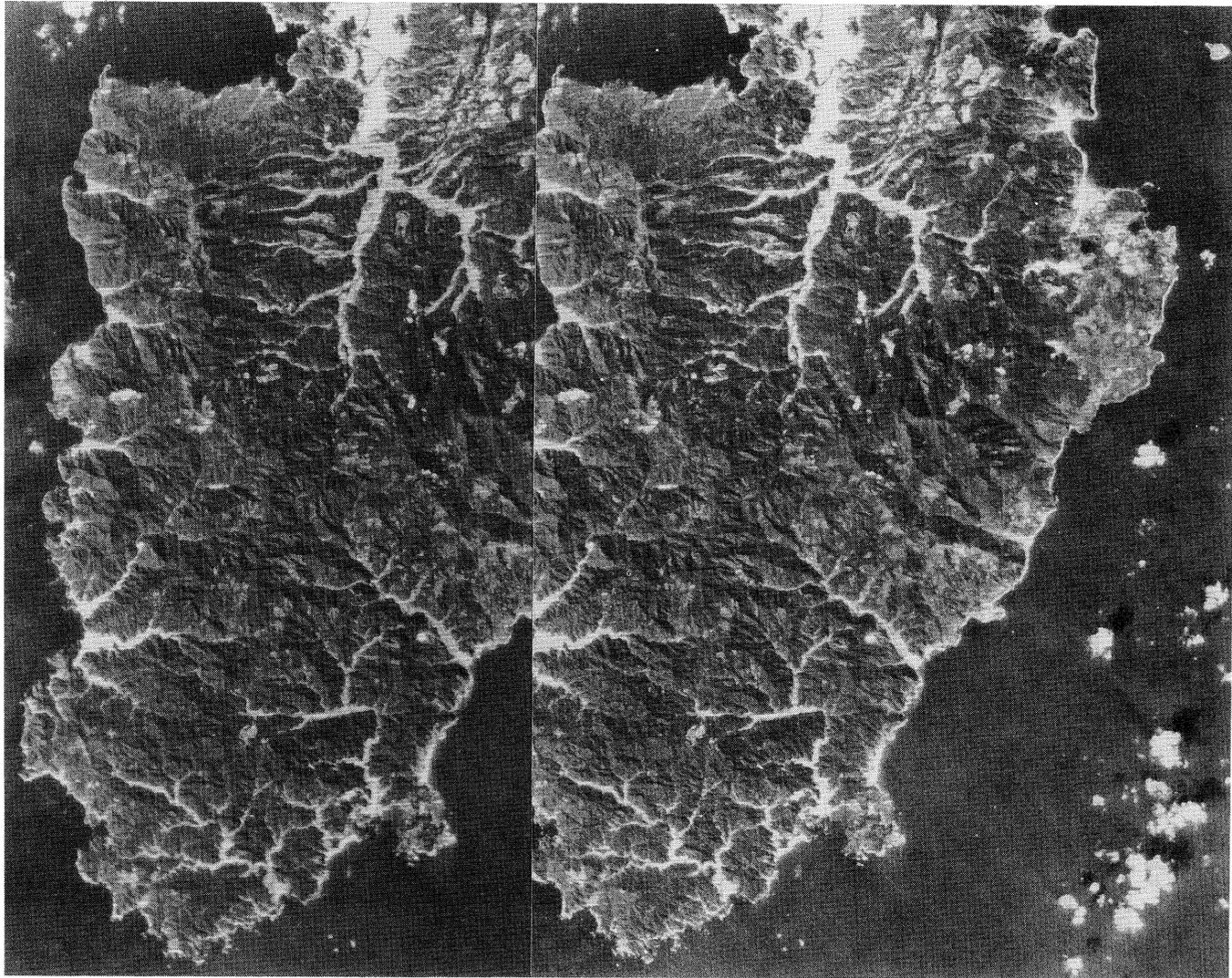


Photo 2 JERS-1 simulation image of the nadir looking sensor

Photo 3 JERS-1 simulation image of the forward looking sensor

It should be noted that the picture element size of the images which we produced as JERS-1 simulation stereoscopic images was 18.3 m x 18.3 m. This means that we produced not raw images but geometrically corrected images because the picture element size of the raw image is 18.3 m x 24.0 m at the nadir looking sensor image and about 19.1 m x 24.0 m at the forward looking sensor image.

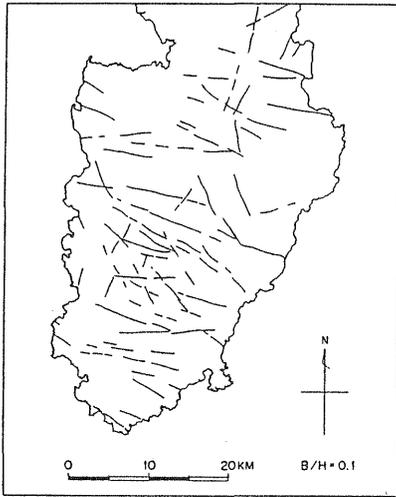
6. Lineament extraction experiment from JERS-1 stereoscopic images

We carried out some experiments to investigate the usefulness of JERS-1 stereoscopic images from the standpoint of the earth resources exploration. One of the results of these experiments is shown in Figure 4. The four maps are the results of lineament extraction from four stereoscopic images which differ in base-to-height (B/H) ratios. These stereoscopic images of different B/H ratios were made by changing the angle of the forward looking sensor at the developed image production system. These lineaments were drawn professionally using a stereoscope. Table 1 shows the total numbers and lengths of these lineaments in each map. From these results we can say as follows.

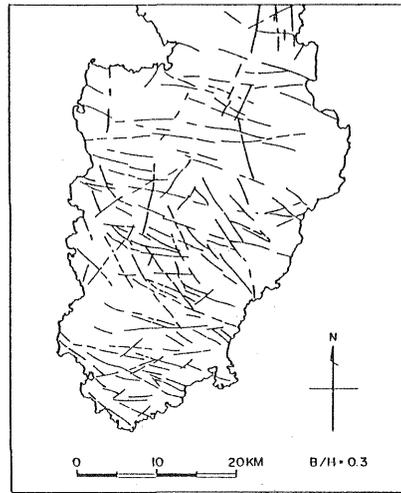
- (1) We can extract the maximum amount of lineaments from 0.5 B/H ratio stereoscopic images, but 0.3 images are not very inferior to 0.5 images.
- (2) The B/H ratio of 1.0 is too large to extract lineaments in this area where the slope of the earth's surface is somewhat steep.
- (3) The B/H ratio of 0.1 is too small to extract lineaments even in this somewhat steep slope area.
- (4) We can extract many unknown lineaments from 0.3 images, so it can be said that the stereoscopic images of JERS-1 are very useful to explore earth resources.

Table 1 Total value of lineaments extracted from four stereoscopic images which differ in B/H ratios

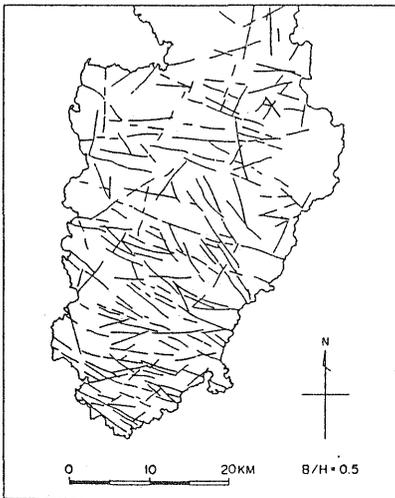
B/H ratio Lineament	0.1	0.3	0.5	1.0
Total number	135	284	330	262
Total length (km)	305.86	594.13	730.10	610.36



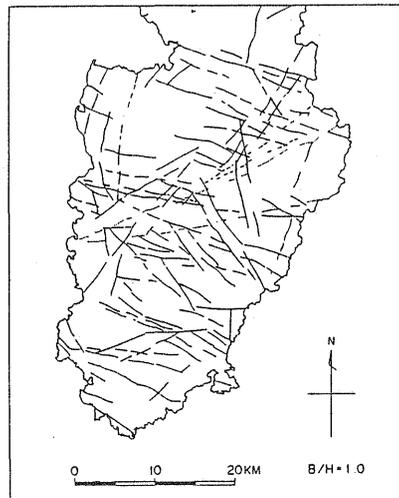
(a) $B/H = 0.1$



(b) $B/H = 0.3$



(c) $B/H = 0.5$



(d) $B/H = 1.0$

Figure 4 Results of lineament extraction from four stereoscopic images which differ in B/H ratios

7. Conclusion

We developed a system to make JERS-1 simulation stereoscopic images from photographs. Using this system, we produced JERS-1 simulation stereoscopic images of the Izu peninsula in Japan from an LFC photograph taken from the space shuttle. From the evaluation of these stereoscopic images, it is confirmed that the stereoscopic images of JERS-1 produce fine stereoscopic vision with acceptable vertical exaggeration, and the ground resolution of JERS-1 is more than acceptable to extract terrain features of the earth's surface.

We carried out some experiments to investigate the usefulness of these images. One of them was lineament extraction from four stereoscopic images with different base-to-height ratios. From these experiments we found that JERS-1 stereoscopic images are very useful to explore earth resources.

But our work has not been sufficient to investigate all the possible applications of JERS-1 stereoscopic images. We hope that many other investigations of JERS-1 stereoscopic images are executed and many application fields of these images are developed.

Reference

Shunji Murai, Ryosuke Shibasaki; Geometric Correction of Linear Array Sensor; Proceedings of International Symposium on Advances in the Quality of Image Data, Com. I, Camberra, Australia, Apr., 1982.