EXTRACTION OF PRECISE ATTITUDE BY MEANS OF IMAGE NAVIGATION CHANNEL DATA OF AVNIR

Kazuyoshi Takahashi and Makoto Ono

Remote Sensing Technology Center of Japan
1-9-9 Roppongi, Minato-ku, Tokyo, Japan

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ABSTRACT

A method for precise geometrical correction of space borne imager is proposed. In the AVNIR (Advanced Visible and Near Infrared Radiometer) to be launched on Japanese earth observation satellite ADEOS has an additional CCD array channel (called as image navigation channel) to be used for this precise geometric correction. Through self closed attitude estimation by using both image data out of the main CCD channels and stripes out of the image navigation channel, precise relative attitude which is enough to correct geometrical distortion due to the satellite or sensor attitude motion can be generated. This paper introduces the principle of operation as well as the simulated result to show the performance of the process.

INTRODUCTION

Till recently, most space borne Earth observing imager data was processed to eliminate geometrical distortion due to the satellite motion using attitude telemetry provided from the satellite bus system. For higher resolution imagers, time intervals of attitude data are insufficient for extracting enough information to correct attitude errors, especially to eliminate vibration effects with high frequency components of attitude change.

In some satellites, additional attitude extraction tools like star trackers are installed to overcome such problems. This introduces another bulky instrument into the restricted satellite volume. Furthermore it doesn't always provide accurate attitude data because the local vibration of the satellite is not always the same as that of the high resolution imagers. Multimission satellites like ADEOS carry many sensor, some of which have mechanically moving components which could cause vibration of in the IFOV of the high resolution imagers.

In this paper, we propose an idea for attitude change extraction through the high resolution imager itself. We present the basic idea and principle of operation as well as the simulated result of attitude change extraction. The system is installed in AVNIR, an instrument carried aboard ADEOS which will be launched in August of this year.

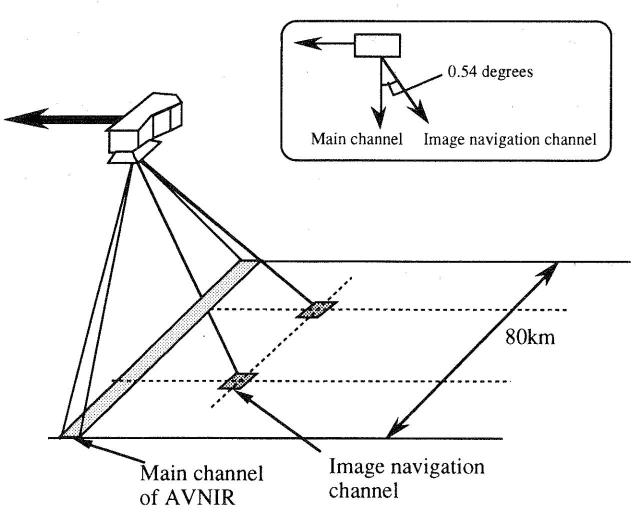


Figure 1 The main and image navigation channels of AVNIR geometry.

ADEOS

The ADEOS satellite acquires global observation data corresponding to environmental changes, such as global warming, destruction of the ozone layer, decrease of tropical rain forests, and occurrence of climatic anomalies. This information is used for international monitoring of the global environment and to develop platform bus and inter-orbit data relay technologies necessary for next-generation Earth observation systems. The satellite will be equipped with core sensors, AVNIR and an Ocean Color and Temperature Scanner (OCTS) developed by the National Space Development Agency of Japan (NASDA), and six sensors from the US, France, MITI and the Environment Agency. The satellite will be launched by an H- II launch vehicle in early 1996 from Tanegashima Space Center. Figure 1 shows the AVNIR channel and Image navigation channel geometry. Table 1 shows AVNIR capabilities.

Table 1 The AVNIR capabilities

		Multispectral	Panchromatic
AVNIR channel	Observation band	1. 0.42 to 0.60 2. 0.52 to 0.60 3. 0.61 to 0.69 4. 0.76 to 0.89	0.52 to 0.69
	IFOV	20 μ rad (16m)	10 μ rad (8m)
	FOV	5.7 ° (80km)	
	S/N	above 200	above 90
	MTF	above 0.25	above 0.20
Image Navigation channel	Quantization bit	8bit	7bit
	Observation band	0.61 to 0.69	
	S/N	above 45	
	MTF	above 0.12	
	FOV direction	0.54 dgrees behind the AVNIR channel	

PRINCIPLE OF OPERATIONS

The basic configuration of the IFOV for the image navigation channel as well as the main channels installed in AVNIR of ADEOS are illustrated in Fig. 1. Main channels are set at the focal plane of the AVNIR optics system. The image navigation channel is a CCD array with the same parameters as the main channel, but the IFOV is slightly separated from the main channel. Due to the data transfer restriction, only a part of the data stream of the image navigation channel is sent back to the ground station to provide two image stripes for this image navigation channel. Since the main channel CCD and the image navigation channel CCD are mechanically set on the same focal plane unit, motion of the IFOV is the same for each of them, but the field of view differs slightly on the ground. By using these image data sets, we can find a stream of corresponding points of a partial of image an image navigation channel on the image of the main channel. Since we have the focal plane parameters, we can calculate the ideal corresponding point of the image navigation channel data on the image of the main channel if there is no attitude change. The difference between the actual corresponding point and the ideal corresponding point is caused by the attitude change between main channel data acquisition and image navigation channel data acquisition. By integrating the derivative position knowledge, we can extract the precise attitude motion of AVNIR.

Figure 2 shows the idea of the above mentioned corresponding point trace of the image navigation channel on the main images. If, as the simplest assumption shown in Fig 2(a), the attitude change is due only to the roll angle, the point corresponding to the ideal point where no attitude change exists, is always offset in the cross track direction. In this case, the time difference between the two channels for the same ground target is constant, so that of attitude changes can be derived easily.

In general, motion change consists of cross track and along track direction changes. In this case, we must separate the difference into three components roll, pitch and yaw, as shown in Fig 2(b). For an along track of corresponding point, theses are differences in attitude as well as time. Time -attitude domain mapping is used to obtain attitude change in the same time interval. Figure 3 shows the idea, the difference in corresponding points is mapped along the time-motion line. By this mapping method, any attitude difference a mean time difference can be calculated by interpolation to derive extract attitude, as be mentioned below. The relative attitude of IFOV is calculated as follows using roll, pitch and yaw attitude difference for the mean time difference of main and image navigation channel data acquisition of the same ground point,.

If the target IFOV motion function is expressed by a function of time t as $f(t)$, the attitude change is expressed as,

$$d(t) = f(t + Ts) - f(t) \quad (1)$$

where Ts is the mean time difference.

By taking the Fourier spectrum of the equation (1),

$$D(\varpi) = F(\varpi)\exp(-j\varpi Tp) - F(\varpi) \quad (2)$$

Thus

$$F(\varpi) = \frac{D(\varpi)}{(1 - \exp(-j\varpi Tp))} \quad (3)$$

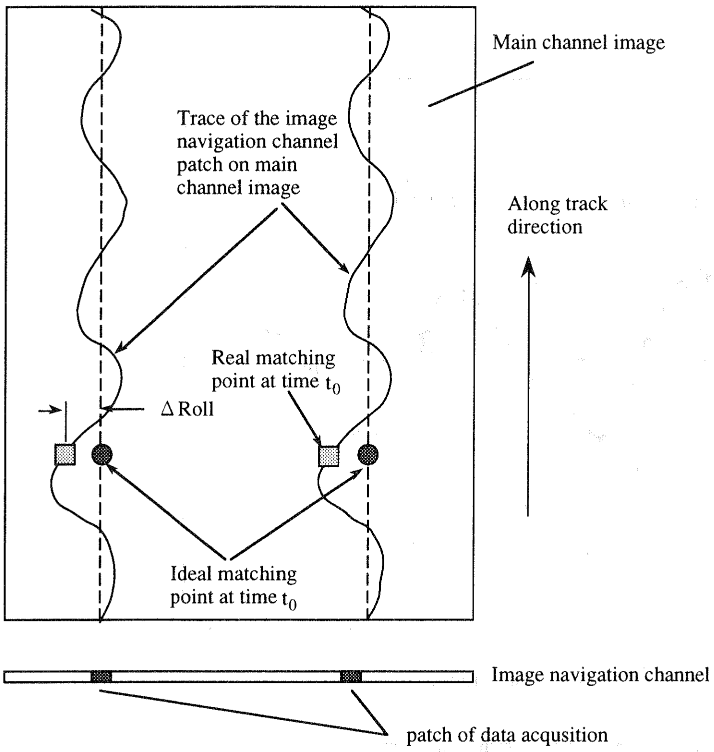


Figure 2(a) Trace of matching points of image navigation channel onto the main image (roll motion only).

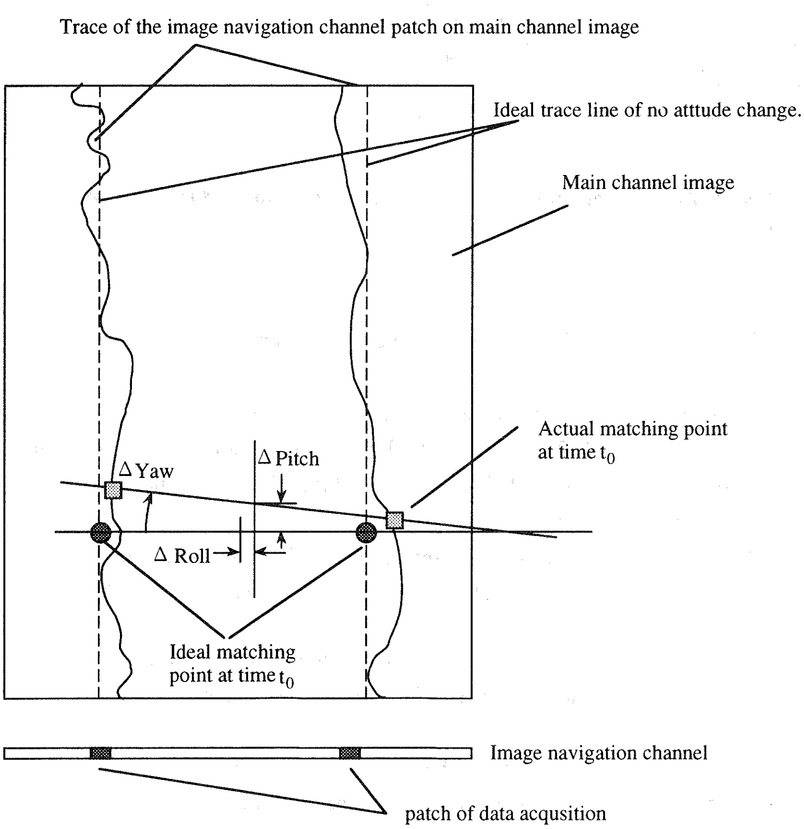


Figure 2(b) Trace of matching points of image navigation channel onto the main image (general case).

From eq. (3), $f(t)$ are deduced by the inverse Fourier transform. In eq. (3), pole will a exist when the ϖTp is $2n\pi$. In our data handling these pole is set to zero.

Along with the attitude change between the data acquisitions, there is a parallax effect caused by the local altitude of terrain witch causes an apparent attitude change. Since the displacements of two channel CCDs are small, the parallax effect is small enough to be neglected or corrected by rough order DEM.

SIMULATION

In this section, we discuss simulating the extraction of the main channel attitude from the attitude of the difference in the main channel and the image navigation channel. In the simulation, the main channel data is random, and image navigation channel is generated from the main channel data with a suitable time delay. The main channel and image navigation channel data consist of 8192 points of random data. If eq. (3) is divergent, eq (3) is set to zero. Figure 4 and Table 2 show the simulated results for time delay equivalent of 160, 320 and 640 pixels along track. In fig. 4 , the ordinate is attitude in radians and the abscissa is time. The solid and broken lines show the main channel attitude and the extracted attitude. The dotted line shows the difference in the main channel attitude and the extracted attitude. The difference between the given and the extracted attitudes consists of two components, one of which is offset component that doesn't affect the attitude correction. The other component is residual component which arises error of the attitude correction. Table 2 shows the relation between the ratio of the average time offsets to total data acquisition time and the residual component. The residual component decreases as the total data acquisition time increases.

In Fig. 4, the main channel attitude data is not a completely periodic function, the bias component vibrates. Therefore, the ratio of time delay is large, and the attitude extraction is inaccurate. In the simulation, the attitude extraction accuracy is 6.5×10^{-6}radian when the ratio of time delay is 4 %. This is equivalent to the 0.52 pixels for images from a satellite

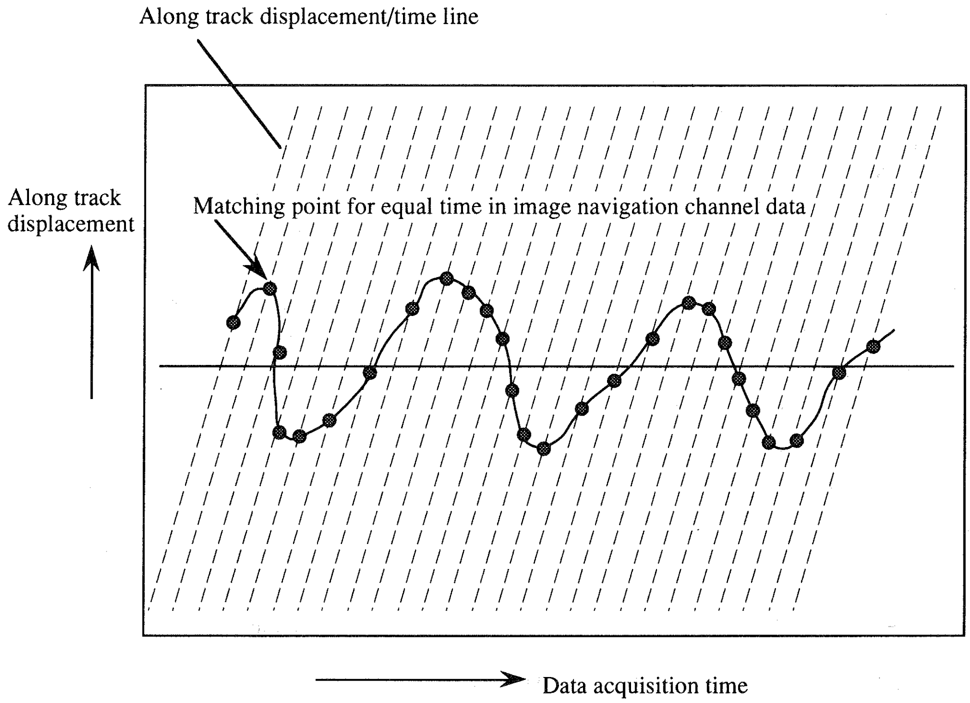


Figure 3 Plot of along track displacement of matching point.

Table 2 The error of estimated attitude to the total data acquisition time

Ratio of the average time offsets to total data acquisition time	The residual components (radian)
1.9%	1.5×10^{-6}
3.9%	6.5×10^{-6}
7.8%	2.95×10^{-5}

altitude of 800km. To extract attitude information using image navigation channel data, the extracting must be about 25 times the time delay.

EXTRACTION OF THE ATTITUDE DIFFERENCE

AVNIR data is not presently available. To analyze the function of image navigation, we simulated a AVNIR image using existing satellite image and tried to extract attitude information from the simulated image. Figure 5 shows the simulated images of the main channel and image navigation channel. The elevation influences in the acquired image of the satellite does not change attitude. However, parallax due to elevation is introduced in the image if the satellite attitude changes. The simulated image Field of View (FOV) changed with the attitude change of the satellite and the parallax due to elevation.

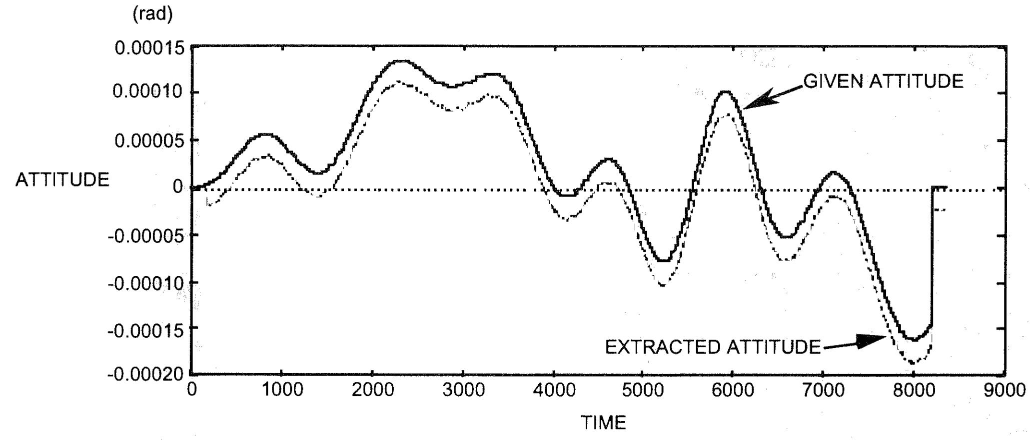
We will now describe how to generate the simulation image using DEM. Figure 6, X is the image acquired with a flat surface, Y is the image with parallax due to elevation, and the satellite is position R. The satellite observes point y in the image Y instead of point x in the image X due to the parallax introduced by elevation. Therefore, we simulated the image from a SPOT image and DEM.

Simulation Conditions

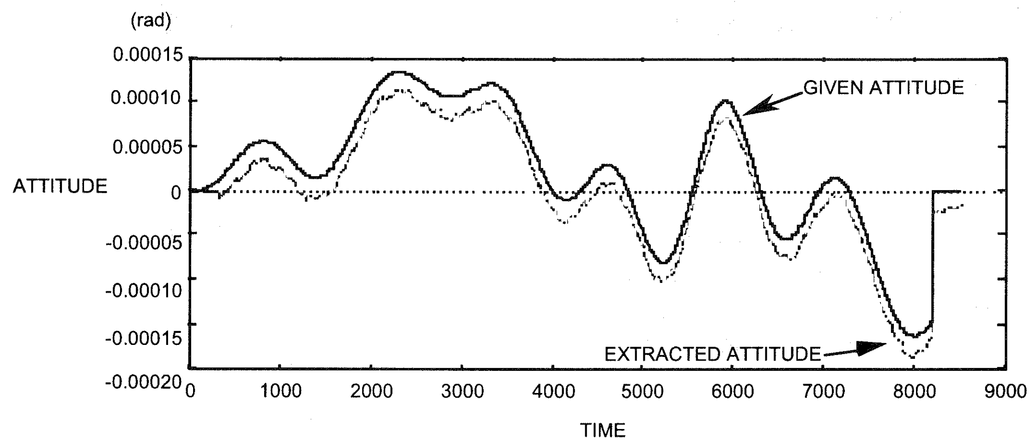
1. The satellite altitude H is 800 km.
2. The satellite velocity V is 7 km/s.
3. The attitude change is only in the roll direction.
4. The FOV of the Image Navigation channel is 0.054 degrees behind the FOV of the AVNIR channel.
5. Pixel size is 10 m (same as SPOT)
6. DEM (Geographical Survey Institute publication)

The main channel simulated image is a 700 line x 700 pixel area around Mt. Fuji in Japan, and the image navigation channel simulated image is a 700 lines x 100 pixel area.

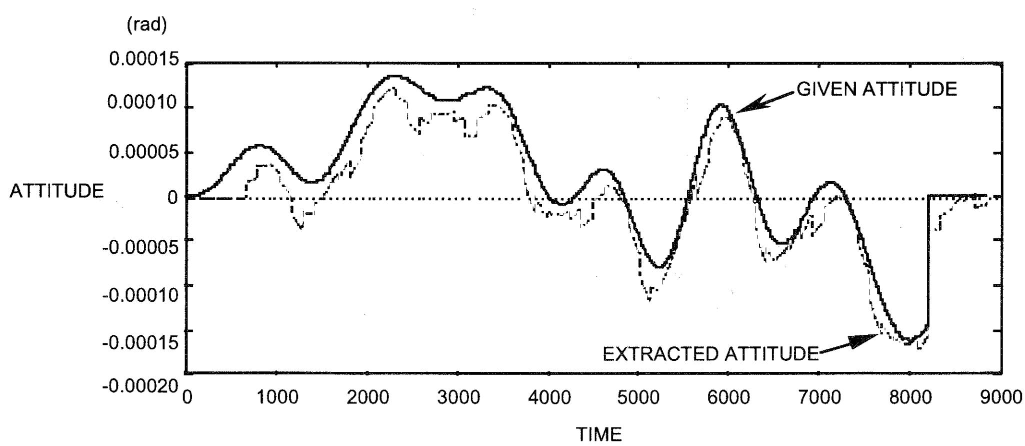
We have shown that the attitude variance of main channel can be extracted by means of image navigation. In image navigation, it is important to extract the precise information about the difference of attitude change between main and image navigation channels. We examined the accuracy of attitude change derived



(a) Time delay equivalent to 160 pixels along track.



(b) Time delay equivalent to 320 pixels along track.



(c) Time delay equivalent to 640 pixels along track.

Figure 4 Simulated result of attitude estimation.

from the simulation image using the image-matching method. In order to simplify the calculation, we used the image correlation method as the image-matching method. In image-matching, matching points with a correlation coefficient of less than 0.99 are neglected, and the matching accuracy is 1 pixel. The matching window size is 3 lines x 41 pixels. Fitting points with a correlation coefficient of less 0.99 are calculated using interpolation from effective fitting points based on the assumption that the attitude change of satellite is very small compared to the satellite movement. The result is shown in Fig. 7. The solid line shows the

Figure 5(a) Simulated image of the main channel around Mt. Fuji.

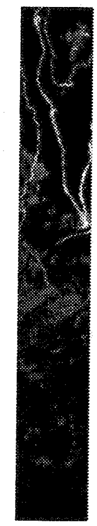


Figure 5(b) Simulated image of image navigation channel.

given data, the dashed line shows the matching result. The difference is calculated by subtracting the given data from the data of matching result. The change of Difference in Fig 7 is 1.12 to -1.15 pixels. The extracted attitude change difference is a fairly good approximation.

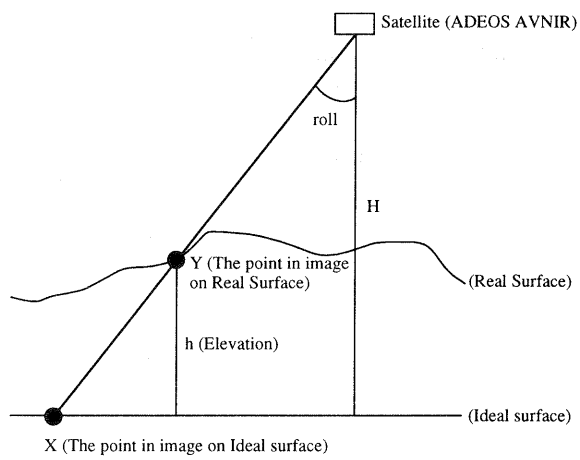


Figure 6 Relation between the ideal and real image of points.

CONCLUSION

Image navigation in which an additional channel is added to the high-resolution imager itself is a powerful tool for extracting IFOV motion of the imager. Simulation by means of SPOT data shows satisfactory results in finding matching point of image navigation channel image point on the main channel image which is key operation for image navigation system. In some cases, image matching accuracy degrades due to the low signal to noise ratio at the vegetated area but is resolved by filtering the estimated raw attitude change data. After the launch of ADEOS, we will process real AVNIR data to verify the image navigation system performance.

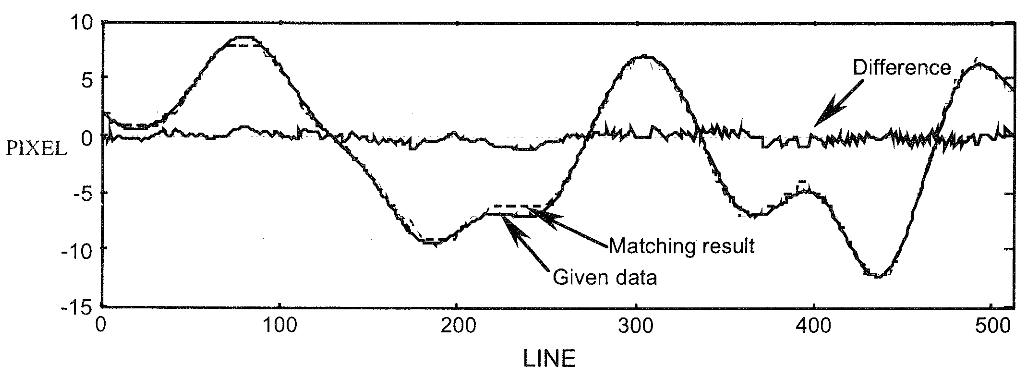


Figure 7 Matching result.

REFERENCE

National Space Development Agency of Japan, (1994). ADEOS REFERENCE HAND BOOK, pp. 11-4 - 11-6.