THE IMAGE PROCESSING SYSTEM FOR JERS-1 OPS

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ABSTRACT:

Japanese Earth Resources Satellite-1(JERS-1) was launched on 11,February,1992.This satellite has two sensors ,Optical Sensor(OPS) and Synthetic Aperture Radar(SAR), and observes earth surface with high resolution. Observed data is downlinked to Earth Observation Center(EOC) of National Space Development Agency of Japan (NASDA). The data is reproduced from High Density Digital Tape(HDDT), and outputted to Optical Disk(OD) or Computer Compatible Tape(CCT) after rectification process.
High spatial resolution of observed image means that high speed and precise data processing are required for data processing system. From this requirement, a dedicated data processing system for JERS-1 has been newly developed.
In this paper, the outline of JERS-1 data processing system and the algorithm of OPS distortion correction are described.

KEY WORDS: JERS-1, OPS, Image Processing, Distortion Correction.

1. THE OUTLINE OF THE PROCESSING SYSTEM

This system has functions to read JERS-1 mission data recorded onto HDDT, execute distortion correction and output to media for storage and distribution (OD ;Optical Disk,CCT;Computer Compatible tape).
This system has various features to perform these functions efficiently as described in the following section.

1.1 Features of the Processing System

Main features of this system are as follows.

(1) High Speed Playback of HDDT
Mission data from HDDT is stored into the memory of the electronic disk directly, so that,it is possible to play back HDDT with the same speed as recording.

(2) Information Exchange with LAN
Required data for distortion correction processing (production order, orbit data etc.) can be inputted with LAN(Local Area Network). And registration of process results to archiving and retrieving system can be also done with LAN.

(3) High Speed Image Correction Equipment
We have two high speed image correction equipments to process huge image data speedy. High speed image correction equipment consists of the electronic disk which is silicon chip memory device with about 1giga bytes storage and the non Von-Neumann type computer called NEDIPS.

(4) Parallel Processing
Controlling two systems of high speed image correction equipments simultaneously, we can process more than two images in parallel at same time to enable furthermore speedy process.
And storing both raw image data and processed image data in another area of the electronic disk, it is able to input image data of next scene while outputing processed image to output media for more speedy processing.

(5) Processing with Workorder
Making production orders for a day as a workorder, it is able to do continuous processing with minimum operations (exchange of media,etc.). So that we can utilize the functions shown by (3) and (4) most efficiently.

(6) Automatic Execution of Pre-inspection
The inspection of the reliability of input data is done automatically. And, the function of calculating cloud quantity automatically are also provided.

(7) Supporting Software
It has functions of check-process for evaluation of OPS and SAR after launch, and database management to maintain and update databases used for processing. So we can maintain the environment for most suitable processing of sensor data.

1.2 Hardware

JERS-1 data processing system consists of the following equipments.
(a) High density digital recorder
(b) Data interface equipment
(c) High speed image correction equipment
(d) Mini-computer system
Figure1.2-1 shows the hardware configuration of JERS -1 data processing system.

1.2.1 High Density Digital Recorder(HDDR)
This equipment plays back HDDT and outputs mission data to the data interface equipment.There are three HDDRs in the system, so that parallel playback of JERS-1 OPS and SAR data is possible.

1.2.2 Data Interface Equipment
This equipment is in charge of the interface between HDDR and the high speed image correction equipment, and consists of the following equipments.

(1) Signal Distributor : Distributes data from HDDR to each synchronizer.
(2) Timing Controller : Controls HDDR (three units for each HDDR).
(3) Synchronizer : Executes frame synchronization of mission data.
(4) Data Switcher : Switches the connection between synchronizer and data formatter.
(5) Data Formatter : converts mission data to the format to store in electronic disk.

1.2.3 High Speed Image Correction Equipment
This equipment consists of the electronic disks and NEDIPSs, and executes high speed processing of image generation and distortion correction.

(1) Electronic Disk : Stores raw data from the data interface equipment and processed image data.
(2) NEDIPS : Executes high speed image generation and distortion correction to raw data in the electronic disk.

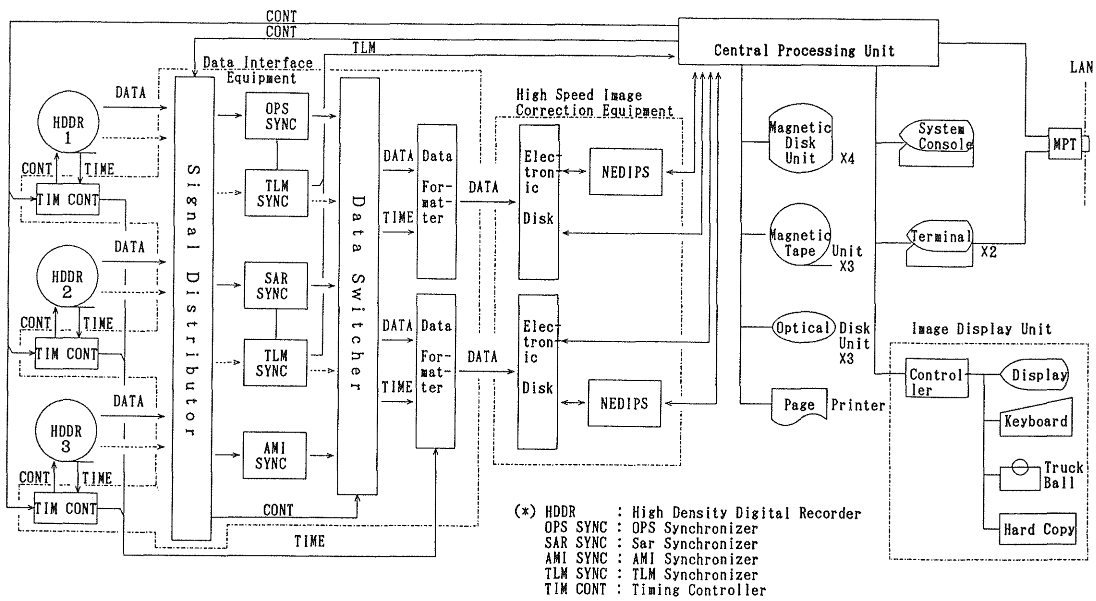


Figure 1.2-1 Processing Facility Hardware Configuration

1.2.4 Mini-Computer System

This Equipment controls the whole of processing system, and outputs the processed image to the optical disk or the magnetic tape.

1.3 Software

Software of JERS-1 data processing system consists of the following softwares.

(1) Image generation and distortion correction software
(2) Check process software
(3) Database management software

1.3.1 Image Generation and Distortion Correction Software

This software consists of two parts.

(1) Distortion Correction Processing Software :
This part performs image generation and distortion correction and outputs image to optical disk or CCT.
(2) Conversion Processing Software :
This part converts the products made in distortion correction processing part to the another media or format.

1.3.2 Check Process Software

This software has image evaluation functions such as image display, statistics calculation and OPS/SAR calibration data processing,etc. for the purpose of checking the status of JERS-1 OPS and SAR.

1.3.3 Database Management Software

This software manages databases used for distortion correction. Sensor characteristics data, constants, GCP(Ground Control Point)data and ephemeris/attitude /telemetry data, etc. are managed as database. And this software evaluates the trend of the characteristics of the sensors.

1.4 The Outline of OPS Distortion Correction

In OPS distortion correction processing, the options for products as shown in table1.4-1 are prepared. The options for product specification are inputted from workorder. Figure1.4-1 shows processing flow of OPS distortion correction.

(1) HDDT Input : This function stores OPS raw image and telemetry into the electronic disk and the magnetic disk respectively, and reads constant used for the distortion correction from databases.
(2) Pre-process : This function converts telemetry into engineering units, and calculates the coefficients of the approximation functions of ephemeris and attitude data.
And this inspects the reliability of inputted data.
(3) Radiometric correction preparation : This function calculates the coefficients for radiometric correction with OPS radiometric characteristics data and sensor temperature data obtained from telemetry.
(4) GCP extraction : In case of processing level3 or 4, this function extracts GCPs from raw image data and estimates the coefficients of the approximation functions of ephemeris and attitude data precisely by using extracted GCPs.
(5) Geometric correction preparation : This function calculates the coefficients for geometric correction with OPS geometric characteristics data, the approximation function of ephemeris and attitude, etc.

Table 1.4-1 Explanation of OPS Product

Process Level	0	1	2	3	4	5
Correction	–	Radiometric Correction - CCD Sensitivity - Dark Current - A/D Converter				
		–	Geometric Correction - Orbit/Attitude - Alignment - Earth(Rotation, Ellipsoid) - Band to band registration - Map Projection			
			–	GCP	RCP	–
Bands	1~8		1~3,5~8			3,4
Map project.	———		UTM,SOM,PS			
Resampling method	———		NN, CC (Pixel Spacing = 18m, 25m)			
Scene size	75km × 75 km (Nominal)					
CCT	Based on CEOS Format 1600/6250bpi-9Track (BSQ/BIL)					
Optical Disk	CCT Base					

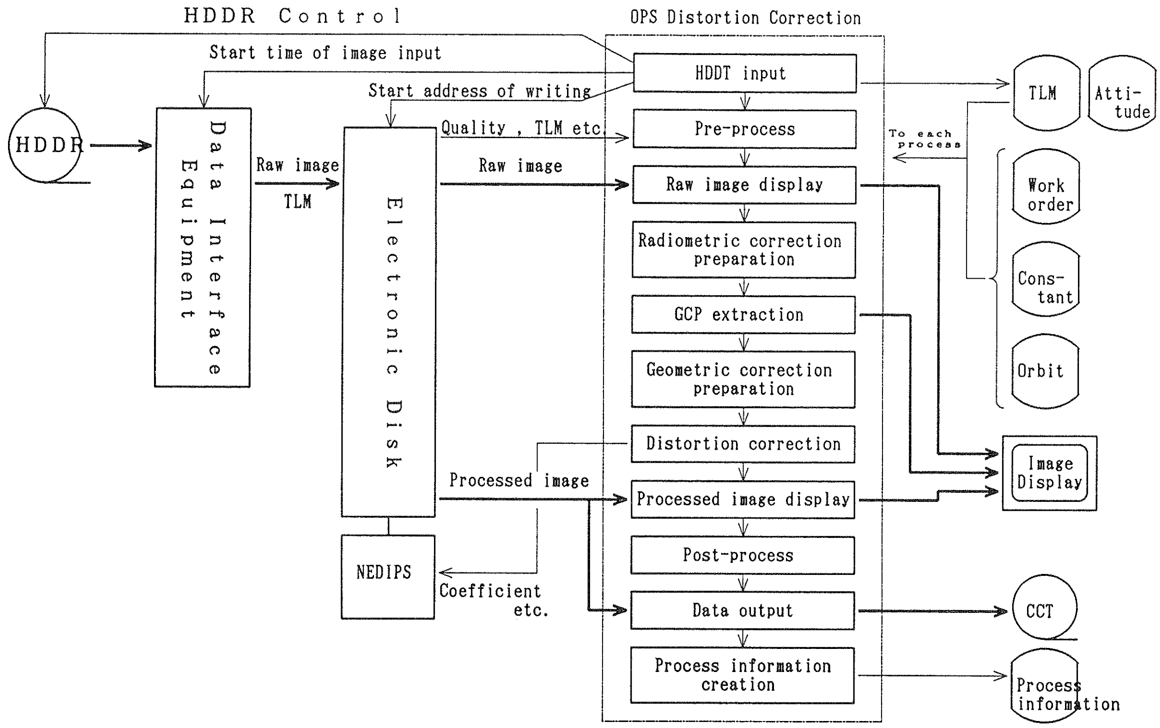


Figure 1.4−1 OPS Distortion Correction process flow

(6) Distortion correction : This function generates corrected image with the coefficients calculated by the above-mentioned process, and stores the image in the electronic disk. Histogram measurement of the image and automatic cloud cover assessment is also carried out.
(7) Post-process : This function edits the information obtained by the above-mentioned process to the format of optical disk or CCT.
(8) Data output : This function outputs processed image and the information edited in the post-process to optical disks or CCTs.

2. OPS RADIOMETRIC CORRECTION

2.1 Radiometric Model

OPS consists of Visible and Near Infrared Radiometer (VNIR) and Short Wave Infrared Radiometer(SWIR). And Each sensor is divided into two components. One is a radiometer which transforms input radiance into voltage, and the other is a signal processor which transforms output voltage from the radiometer into digital number. Figure2.1-1 shows radiometric model used for correction in the processing system. In this figure, radiometric noises occur at each components are also shown. Considering noises in figure2.1-1, digital output number of OPS is expressed as following equations.

$$V = Q \cdot Ks \cdot Kt \cdot Kr + V_0 \qquad (1)$$
$$D = [\, a \cdot V + b \,] \qquad (2)$$

where
$V(i,j,d,td)$:pre-amp output(mV)
$Q(i,j)$:input radiance($W/m^2 \cdot str \cdot \mu m$)
$Ks(j,d)$:sensitivity coefficients($mV/W \cdot m^{-2} \cdot str^{-1} \cdot \mu m^{-1}$)
$Kt(j,d,t_d)$:sensitivity dependence on detector temperature
$Kr(i,j,d)$:sensitivity deviation among elements
$V_0(i,j,d,t_d)$:offset voltage(mV)
$D(i,j,d,t_d,g,s,t_p)$:signal processor output
$a(j,d,g,s,t_p)$:gain of signal processor(/mV)
$b(j,d,g,s,t_p)$:offset of signal processor
i:pixel(element) number
j:band number
d:distinction of odd/even element
t_d:temperature at detector(° C:VNIR, K:SWIR)
g:distinction of normal/high gain
s:distinction of A/B system of signal processor
t_p:temperature at signal processor
[]:quantizing

2.2 Determination of Correction Coefficients

Each coefficients in equation(1),(2) are determined with the pre-flight data which was acquired in the OPS pre-flight test.

2.2.1 Sensitivity Coefficient:Ks(j,d)

Ks means input/output characteristics at the reference elements of CCDs. In the pre-flight test, pre-amp output voltage for several input radiance values was measured. With these data, Ks is calculated by least square approximation.

2.2.2 Sensitivity Deviation:Kr(i,j,d)

Difference of input/output characteristics among the elements of CCD causes variance of pre-amp output voltage for uniform input radiance. Kr is defined as a ratio of output voltage at a specified element to the one at reference element. It may be assumed that Kr has no dependence on detector temperature. In the pre-flight test, pre-amp output voltage for uniform input radiance was measured for all elements. This voltage includes offset voltage which is due to dark current,etc.,and should be removed. Therefore, Kr is determined from following equation.

$$Kr(i,j,d) = \frac{Vd(i,j) - Vo(i,j,d,t_r)}{Vd(i_r,j) - Vo(i_r,j,d,t_r)} \qquad (3)$$

where
V_d:pre-amp output voltage(mv)
V_o:offset voltage(refer to 2.2.3)

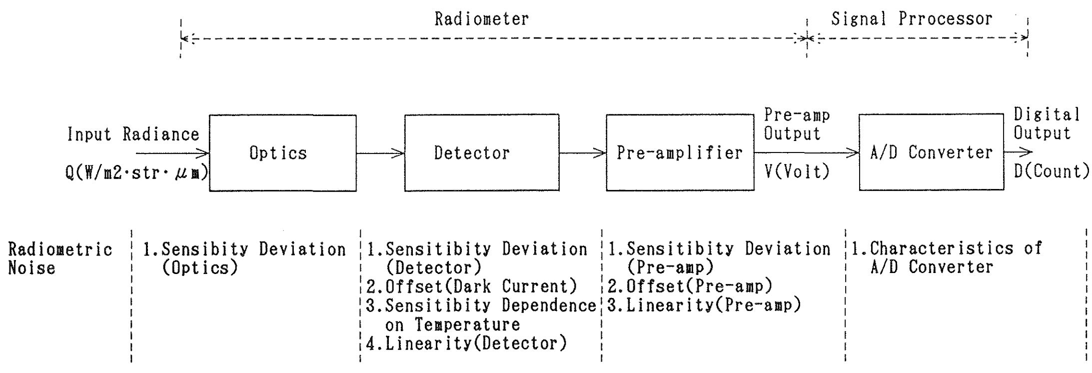


Figure2.1-1 OPS Radiometric Model

i_r:reference element number 2048(d=even)
2049(d=odd)

t_r:detector temperature at output voltage measurement(VNIR:° C,SWIR:K)

2.2.3 Offset Voltage:$Vo(i,j,d,t_d)$

Offset voltage includes dark current of the detector and offset of the circuits. The amount of dark current depends on detector temperature. Offset voltage is expressed as following equations.

VNIR:

$$Vo(i,j,d,t_d)=Vp(j,d)+Vc(i,j)\cdot 2^{dc(i,j)\cdot(td-tc)} \quad (4)$$

SWIR:

$$Vo(i,j,t_d)=Vc(i,j)+dc(j)(t_d-t_c) \quad (5)$$

where

Vo:offset voltage(mV)
Vp:offset of circuit(mV)
Vc:standard voltage(mV)
dc:dark current coefficient
t_c:detector temperature at standard voltage measurement

2.2.4 I/O Characteristics of signal processor:a,b

These coefficients mean input/output characteristics of A/D converters in signal processor. In the preflight test, output digital number corresponding to input voltage was measured. Coefficients a and b are determined from these data with least square approximation.

2.3 Radiometric Correction Equation

From equations (1) and (2), radiometric correction equations which calculate input radiance from output digital number are derived as follows.

$$V=\frac{D-b}{a} \quad (6)$$

$$Q=\frac{V-Vo}{Ks\cdot Kt\cdot Kr} \quad (7)$$

In order to store input radiance Q in CCT with 1byte (8bits), Q is multiplied by scale factor (Dm/Qm) and quantized as following equation.

$$Dc(j,g)=\left[\frac{Dm(j,g)}{Qm(j)}\cdot Q\right] \quad (8)$$

where

[]:quantizing
Dc(j,g):digital number after radiometric correction
Qm(j):maximum input radiance for each band ($W/m^2\cdot str\cdot\mu m$)
Dm(j,g):maximum digital number corresponding to gain of signal processor for each band

The inverse of scale factor (Qm/Dm) is recorded in the radiometric ancillary record of OPS CCT, so that users can convert digital number to input radiance Q by using this data.

2.4 In-flight Calibration

OPS has following three operation mode.
a) observation mode
b) electrical calibration mode
c) optical calibration mode.

By using OPS image data acquired in each operation mode, in-flight Calibration of radiometric correction coefficients will be done.

3. OPS GEOMETRIC CORRECTION

3.1 The Procedure of Geometric Correction

3.1.1 The outline of Geometric Correction

OPS raw image includes geometric distortion due to orbit/attitude variance of the platform, misalignment of the sensors and earth rotation effect, etc. In order to remove these geometric distortion from image, the relationship between raw image coordinate system and geometrically corrected image coordinate system is formulated with several coordinates transform. Figure3.1-1 shows this concept.
With this formula, corrected image is generated from raw image by the interpolation method called the resampling.
As shown in figure3.1-1, this formula is transform from corrected image to raw image, so the inverse functions of F1～F4 is necessary.
But it is impossible to derive the inverse function of F1 analytically. Therefore, raw image coordinates corresponding to specified point on corrected image is determined by iteration process with F1～F4.

3.1.2 Determination of Correction formula

In the method used for OPS geometric correction, corrected image coordinate system is divided into several blocks. Then, bi-linear transform equation, which calculates raw image coordinates corresponding to specified point on corrected image, is determined for each block(see figure3.1-2). Bi-linear tarnsform

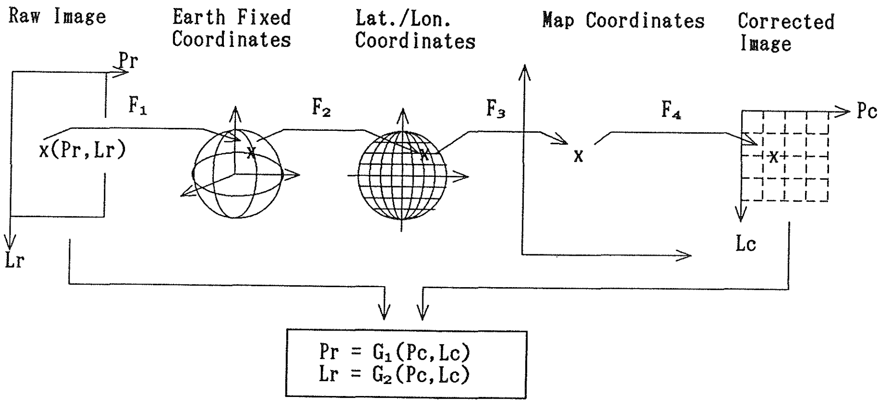
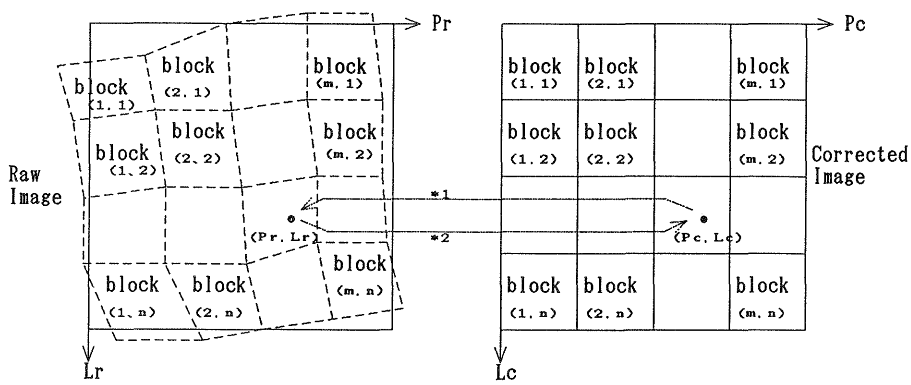


Figure3.1-1 Concept of Geometric Correction



$$*1 \begin{cases} Pr = a\cdot PcLc + b\cdot Pc + c\cdot Lc + d \\ Lr = e\cdot PcLc + f\cdot Pc + g\cdot Lc + h \end{cases}$$

$$*2 \quad g(Pc,Lc) = \Sigma h(Pr'-Pr,Lr'-Lr)_{Pr',Lr'}\cdot f(Pr',Lr')$$

Figure3.1-2 Division into Blocks for Resampling Process

equation is expressed as follows.

$$Pr=a(i,j)PcLc+b(i,j)\cdot Pc+c(i,j)\cdot Lc+d(i,j) \quad (9)$$
$$Lr=e(i,j)PcLc+f(i,j)\cdot Pc+g(i,j)\cdot Lc+h(i,j) \quad (10)$$

where
- (Pr,Lr):address on raw image coordinates corresponding to (Pc,Lc)
- (Pc,Lc):address of specified point on corrected image coordinates
- a~h:coefficients of bi-linear transformation equation
- i:block number of pixel direction
- j:block number of line direction

Coefficients from a to h are determined according to the following procedure.
(1) Determine corrected image coordinate system on map coordinate system by using F1~F4.
(2) Divide corrected image into several blocks, and calculate address of four vertexes(called lattice point) of each block.
(3) calculate raw image coordinates corresponding to lattice point on corrected image with iteration by using F1~F4.
(4) With address calculated as above, determine coefficients of bi-linear transform equation for each block.

3.2 OPS Geometric Model

The coordinates transform function F1 is expressed as geometric model specified several coordinate systems in fugure3.2-1.
From figure3.2-1, raw image data P(p,l) observed at time(t) is given as observation position vector G(t) in the following equation.

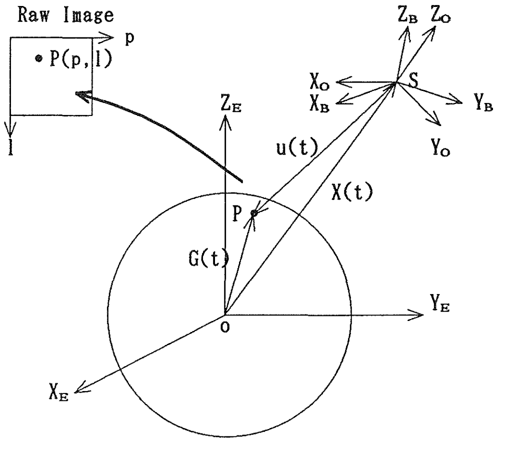
$$P(p,l)=G(t)=G\{\ X(t),\theta(t),\beta(t)\ \} \quad (11)$$

where
- P(p,l):raw image coordinates
- G(t):observation position vector
- X(t):satellite position vector
- θ(t):satellite attitude error angle
- β(t):scanning angle
- t:observation time of P(p,l)

3.2.1 Estimation of Orbit and Attitude
Satellite position vector and attitude error angle in equation(11) are estimated as follows.

(1) Satellite Position Vector:X(t)
Ephemeris data is obtained at intervals of 1 minute from Mission Management Organization in NASDA EOC. This data is interpolated at intervals of 1 second, and then approximated with the third expression.

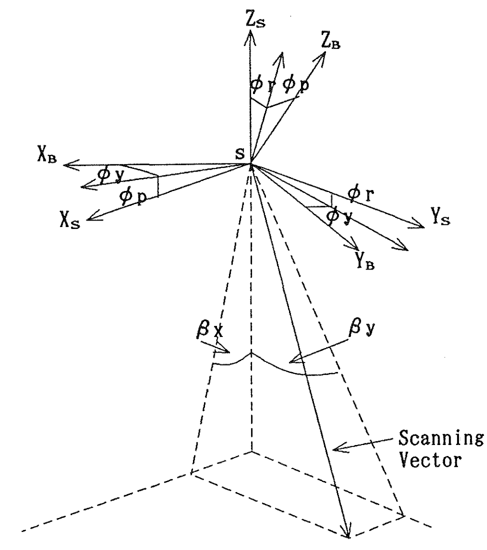
(2) Satellite Attitude Error Angle:θ(t)
Satellite attitude error angle data is in telemetry which is multiplexed to OPS mission data. From this data, the approximation function for satellite attitude error angle is determined.



S:Satellite
O:Earth Center
(X_E, Y_E, Z_E):Earth Fixed Coordinate System
(X_O, Y_O, Z_O):Orbit Reference Coordinate System
(X_B, Y_B, Z_B):Satellite Coordinate System

G(t):Obsrevation Position Vector
u(t):Scanning Vector
X(t):Satellite Position Vector

Figure3.2-1 Geometric Model



S:Satellite
(Xs,Ys,Zs):Sensor Coordinate System
(X_B, Y_B, Z_B):Satellite Coordinate System
βx, βy:Scanning Angle (with Misregistration between Bands)
ϕr, ϕp, ϕy:Misalignment Angle

Figure3.2-2 Scanning Angle

3.2.2 Determination of scanning angle

As shown in figure3.2-2, scanning angle in satellite coordinate system is determined by misalignment(ϕr, ϕp, ϕy) , and scanning angle(βx, βy) in sensor coordinate system.

(1) Misalignment:(ϕr, ϕp, ϕy)
Misalignment is defined as the angle between mission equipment coordinate system and satellite coordinate system (NASDA,1991). VNIR and SWIR are mounted on the satellite separately, so that, misalignment of VNIR and SWIR are measured independently in the pre-flight test.
These data are going to be updated with actually observerd image by using GCPs.

(2) Scanning angle:(βx, βy)
Scanning direction is determined by two scanning angles(βx, βy).These angles are the function of CCD element number, and have characteristics of image distortion caused by the detector alignment and the optics aberration,etc. Scanning angles(βx, βy) are formulated for each band as follows.

$$\beta x=\lambda+d\beta x \qquad (14)$$
$$\beta y=\tan^{-1}\{d/f\cdot(u_c-u)\}+d\beta y \qquad (15)$$

where
- λ:nominal off-nadir angle for along track direction(deg.)
  - λ=0(deg.) for VNIR band1,2 and 3
  - λ=15.33(deg.) for VNIR band4
  - $\lambda=\tan^{-1}\{L/f\}$ for SWIR
- L:distance between CCD and the optical axis
- $d\beta x$:error angle from nominal scanning direction for along track direction(deg.)
- $d\beta y$:error angle from nominal scanning direction for cross track direction(deg.)
- d:interval of sensor element(mm)
- f:focal length of the optics
- u_c:number of center element(=2048.5)

Error angles ($d\beta x$,$d\beta y$) are measured at five points of CCD for each band with changing temperature in the pre-flight test, and approximated as a function of CCD element number and temperature of the optics. The coefficients of the approximation function are going to be updated with actually observed image by using GCPs.
With this function, misregistration between bands also can be corrected.

3.3 Precise Correction with GCPs

In precise geometric correction mode (level3 and,4), ephemeris and attitude data are accurately estimated with GCP(Ground Control Point)s.

3.3.1 GCP Extraction

For GCP extraction from raw image, manual extraction mode and automatic extraction mode are prepared.
In automatic extraction mode,GCP matching is carried out by Cross-Correlation method without operation.

3.3.2 Estimation of ephemeris and attitude data

As described above,the coordiates transform function F1 is the function of orbit and attitude, therefore it is neccessary for precise geometric correction to estimate ephemeris and attitude data accurately by using GCPs.
In OPS precise correction, Newton-Raphson method is used for the estimation.

3.4 Resampling

In order to produce a geometrically corrected image, raw image coordinates corresponding to specified point on corrected image is calculated according to equation(9) and (10). But the result of calculation comes to a real number, so that an interpolation of raw image data(resampling) is required for determining the intensity on specified point on corrected image coordinates.

3.4.1 Resampling method

Generally the equation of resampling is expressed as follows.

$$g(x,y) = \Sigma h(u'-u,v'-v)_{u',v'}\cdot f(u',v') \qquad (16)$$

where

g(x,y):intensity on corrected image (x,y)
f(u',v'):intensity of raw image on (u',v')
h:weighting function
(u,v):raw image coordinates corresponding to (x,y)

In OPS geometric correction, the cubic convolution method and the nearest neighbor method are used for weighting function.

3.4.2 Correction of SWIR staggered arrays

Even and odd elements of SWIR CCD are arranged in 2 staggered arrays. This arrangement causes an aberration of about 1.5 pixel along the satellite flight direction.
This aberration is considered in the interpolation of line direction.

4. CONCLUSIONS

The outline of JERS-1 data processing system and OPS distortion correction algorithm have been described.
This system has the following features,
(1) High speed processing by using the newest digital processing technologies.
(2) The introducing of parallel processing concept.
(3) Minimum operation by automatic execution of the process.
(4) The adoption of the new algorithm of the optical sensor such as the correction of SWIR staggered arrays.
and realizes high speed and precise data processing for JERS-1 OPS.
From now on, we intend to tune up the parameter used in OPS distortion correction for the purpose of more precise data processing.

5. REFERENCES

a) NASDA, 1991. Japanese ERS-1 to Ground Station Interface Description, HE-88023.