

Prepared by CMA  
Agenda Item: B.2  
Discussed in WG II

## **AUTOMATIC NAVIGATION OF FY-2 GEOSYNCHRONOUS METEOROLOGICAL SATELLITE IMAGES**

### Summary and purpose of paper

An automatic image navigation algorithm for FY-2 geosynchronous meteorological satellites was realized in NSMC. Parameters and coordinates used in FY-2 spin geosynchronous meteorological satellite image navigation are derived, with emphasis on attitude parameters. The solution to the navigation model does not depend on any landmark matching. Image navigation quality of FY-2 geosynchronous meteorological satellites was greatly improved.

# AUTOMATIC NAVIGATION OF FY-2 GEOSYNCHRONOUS METEOROLOGICAL SATELLITE IMAGES

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**KEY WORDS:** Image, Navigation, Attitude, Misalignment

## ABSTRACT

An automatic image navigation algorithm for FY-2 geosynchronous meteorological satellites was realized in NSMC. Parameters and coordinates used in FY-2 spin geosynchronous meteorological satellite image navigation are derived, with emphasis on attitude parameters. The solution to the navigation model does not depend on any landmark matching.

In the time series of sub-satellite line count, there is information on the orientation of spin axis of the satellite and the pitch component of the misalignment. With this information, the orientation of the spin axis of the satellite expressed as declination and right ascension (has diurnal variation) and the pitch component of the misalignment (has no diurnal variation) can be solved simultaneously.

In the time series of the image deformation from central column calculated by the  $\beta$ angle, there is information on roll (has no diurnal variation) and the yaw (has diurnal variation) components of the misalignment. With this information, the  $\beta$ angle and the roll and yaw components of the misalignment can be solved simultaneously.

The above way of solution to the navigation model for the navigation parameters needs accurate knowledge on astronomical parameters and coordinate transitions. The orbital, attitude, misalignment and beta angle parameters are turned out automatically and routinely without any manual operation. The automatic image matching routine gets convergence quickly, and quality control of the routine performance becomes an easy job. Image navigation quality of FY-2 geosynchronous meteorological satellites was greatly improved.

## 1. INTRODUCTION

The mathematical model for image navigation of geosynchronous meteorological satellites was originally developed at Space Science and Engineering Center (L.N.Hambrick & D.R. Phillips 1980). In the algorithm of SSEC (SSEC, 1986), landmark matching is an essential component for the solution of the model. However, landmark-matching method does not fit the FY-2 operation. In the Asia monsoon region, clouds often cover landmarks. In summer, it is often difficult to choose a proper set of landmarks over the eastern Asia and the northwestern pacific regions. With no use of any landmarks, the NSMC algorithm gained geographical grids that

match the images at pixel level. This paper introduces the NSMC automatic image navigation algorithm used in the navigation of FY2B images.

## 2. NAVIGATION PARAMETERS

Thirteen parameters are needed to describe geometric orbit and attitude for a spin geosynchronous meteorological satellite:

- Six orbital parameters (inclination, right ascension of the ascending node, semimajor axis, eccentricity, argument of perigee, mean anomaly at epoch);
- Three attitude parameters (declination and right ascension of the spin axis, spin angular velocity);
- Three misalignment parameters (pitch for north-south displacement, roll for total skew effect, yaw for east-west displacement); and
- One  $\beta$  angle parameter (angle of VISSR from viewing the sun, to viewing the earth).

In the above thirteen parameters, spin angular velocity is known. Six orbital parameters are gained from three ranging stations. This paper will not refer to the solution of six orbital parameters. It is assumed well known.

In the NSMC way of solution, the two orientation parameters for the spin axis are solved together with the pitch misalignment parameter; the  $\beta$  angle parameter are solved together with the roll and yaw misalignment parameters. Section 3 and 4 describe the NSMC ways to get those two solutions.

## 3. NAVIGATION MODEL FOR SPIN AXIS ORIENTATION AND PITCH MISALIGNMENT

FY-2 is a spin stabilized geosynchronous meteorological satellite. Figure 1 is a scheme diagram of FY-2 observation geometry. In Figure 1, O is the earth center, N the arctic pole and S the Antarctic. The line links arctic and Antarctic is the axis of the rotating Earth. In Figure 1, we also see the axis of the rotating satellite. In an ideal condition, the orbit of the satellite should be in the equatorial plane; the axes of the satellite and the earth should be parallel. In practice, the orbit of the satellite is not in the equatorial plane (this paper will not refer to the orbital solution), and the axes of the satellite and the earth are not parallel. Suppose that the axes of the satellite and the earth keep their own orientations in the celestial sphere. In a time period of one day, there are always two twinkling at which the axes of the satellite and the earth are in a same plane. Suppose those two twinkling are 06z and 18z. In Figure 1, we see that at 06z (18z) the satellite looks up (down) at the earth, the earth is in the downward (upward) part of the image. At 00z (12z), the scan line passing the sub-satellite point is not parallel with the latitudinal line. This is because the axes of the satellite and the earth are not parallel. The phenomena described above reflect the impact of satellite attitude at the imaging process.

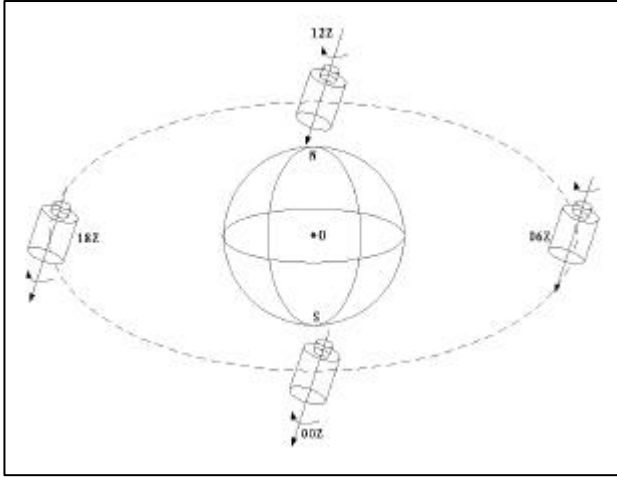


Figure 1. Scheme diagram of FY-2 observation geometry

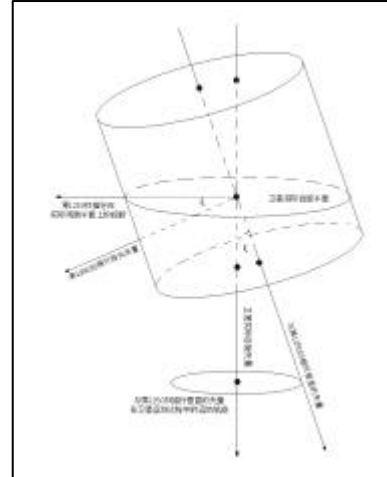


Figure 2. A diagram of the pitch misalignment

Figure 2 is a diagram of the pitch misalignment. FY-2 spacecraft is a column body. In manufacturing, its principle axis should be also its freedom axis with the maximum spin angular momentum. The 1250th scan line should be perpendicular to the principle axis of the spacecraft. With the spin of the spacecraft, the 1250th scan line should scan out a plane. In practice, there are two types of misalignment: the misalignment of the VISSR radiometer axis from the principle axis of the spacecraft and the misalignment of the principle axis from the actual spin axis of the spacecraft. The former is due to the inaccuracy at assembling. The later is due to the mass distribution change of the spacecraft in space. Both the misalignments can be modeled as one effect. Due to the misalignment, the 1250th scan line scan out a cone actually. The shape of the cone can be measured by an angle between the actual spin vector of the spacecraft and the vector perpendicular to the 1250th scan line in a plane consists of the 1250th scan line and the actual spin vector of the spacecraft. This angle is defined as pitch component of the misalignment. Misalignment is very small. But due to the far distance of the spacecraft from the earth, the impact of the misalignment is not neglectful. Images are taken when the VISSR radiometer faces to the earth. Thus the impact of pitch misalignment to the imaging process has no diurnal variation. Figure 3 shows the impact of pitch misalignment at imaging process. If the cone consists of the 1250th scan line is to the northern (southern) side of the actual scan plane, the pitch misalignment is defined as a positive (negative) value, the earth disk is in the southern (northern) side of the image.

In summary, attitude parameters have diurnal variation, while pitch misalignment has no diurnal variation. Based on this concept, SSEC (L.N.Hambrick & D.R.phillips, 1980) established a mathematical model for the solution of spin axis orientation and pitch misalignment. The model can be briefly described as follows:

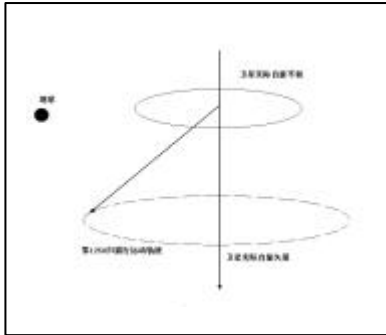


Figure 3. A diagram of the impact of pitch misalignment at imaging process

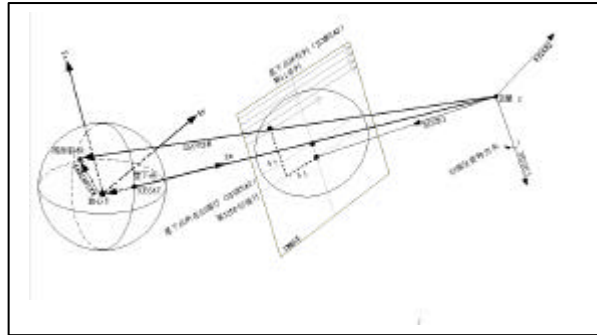


Figure 4. A scheme diagram of the mathematical model for the solution of spin axis orientation and pitch misalignment

Figure 4 is a scheme diagram of the mathematical model for the solution of spin axis orientation and pitch misalignment. In Figure 4, E is the earth center. S is the satellite.  $\mathbf{E_x}$  is the vector from the earth center to the satellite.  $\mathbf{E_z}$  is the vector perpendicular to  $\mathbf{E_x}$  in the plane consists of the satellite and the meridian passing the sub-satellite point.  $\mathbf{E_y} = \mathbf{E_z} \times \mathbf{E_x}$  is from the earth center to the east.  $\mathbf{VISSR3}$  is a vector perpendicular to the 1250th scan line in the plane consists of the 1250th scan line and the satellite spin axis. Plane IMAGE passes through any point along the line from the satellite to the earth center and consists of vectors parallel to  $\mathbf{E_y}$  and  $\mathbf{VISSR3}$ . Observation vector  $\mathbf{SATVIEW}$  is from the satellite to the observation target. The cross point of  $\mathbf{SATVIEW}$  and plane IMAGE is the position of observation target on the image. This can be expressed as:

$$\mathbf{SATVIEW} \cdot \mathbf{VISSR3} = \cos(j + z) \tag{1}$$

$f + ?$  is angle between vectors  $\mathbf{SATVIEW}$  and  $\mathbf{VISSR3}$ .  $f$  is angle between vectors  $\mathbf{SATVIEW}$  and the actual satellite spin axis.  $?$  is angle between vectors the actual satellite spin axis and  $\mathbf{VISSR3}$ , e.g. pitch misalignment.  $f + ?$  can be measured on the image, written as:

$$j + z = \frac{P}{2} - (I - 1250) \cdot P$$

P is step angle between observation lines. Solve equation (1), we can get the spin axis orientation  $\mathbf{VISSR3}$  and the pitch misalignment  $z$ . In the NSMC algorithm, earth center time series rather than landmarks are used at the solution of equation (1).

The north-south displacement and a major part of the total skew effect of the images are then solved. The east-west displacement of the images and the rest part of the total skew effect of the images are discussed in section 4.

#### 4. NAVIGATION MODEL FOR $\beta$ ANGLE AND THE ROLL AND YAW MISALIGNMENTS

Spin geosynchronous meteorological satellites use the sun to align each scan line.  $\beta$  angle parameter (angle of VISSR from viewing the sun, to viewing the earth) is used in the alignment. Knowledge on astronomy and spin axis orientation is needed at the solution of  $\beta$  angle. Figure 5 is a scheme diagram to get  $\beta$  angle.

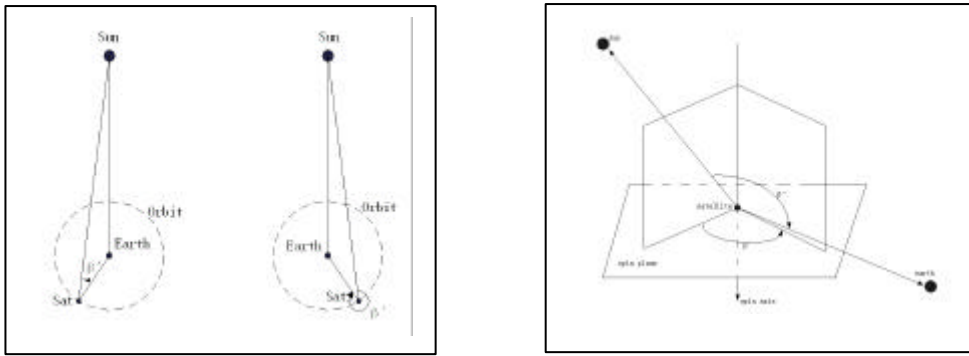


Figure 5. A scheme diagram to get  $\beta$  angle

Figure 5 a (left) shows how to get angle sun-satellite-earth ( $\beta'$ ) with astronomy knowledge. Figure 5 b (right) shows how to get the projection of  $\beta'$  at the satellite spin plane. The  $\beta$  angle is defined as the projection of  $\beta'$  at the VISSR scan plane that is a little different from the projection of  $\beta'$  at the satellite spin plane. The difference is due to the roll and yaw misalignment. It is noticed that in the earth shape deformation, there is information on the roll misalignment that has no diurnal variation; and that in the earth disk east-west shift on the image, there is information on the yaw misalignment that has diurnal variation. In the NSMC algorithm, when the earth shape deformation is detected, the roll misalignment is gained; when the earth disk east-west shift is corrected, the yaw misalignment is gained.

## 5. COORDINATE TRANSFORMATION

The parameters used in the navigation model are defined in the specific coordinate systems. In the coordinate systems where parameters are defined, the parameters may not be conservative with time. In order to get conservative parameters, a series coordination transformations are made in the solution of the navigation model. Total number of coordinate systems used in the navigation model is thirteen.

## 6. RESULT

Figure 6 shows navigation result. The navigation accuracy reached 1-2 IR pixel. Further improvements are made. At the meeting a movie of FY-2B images will be shown.

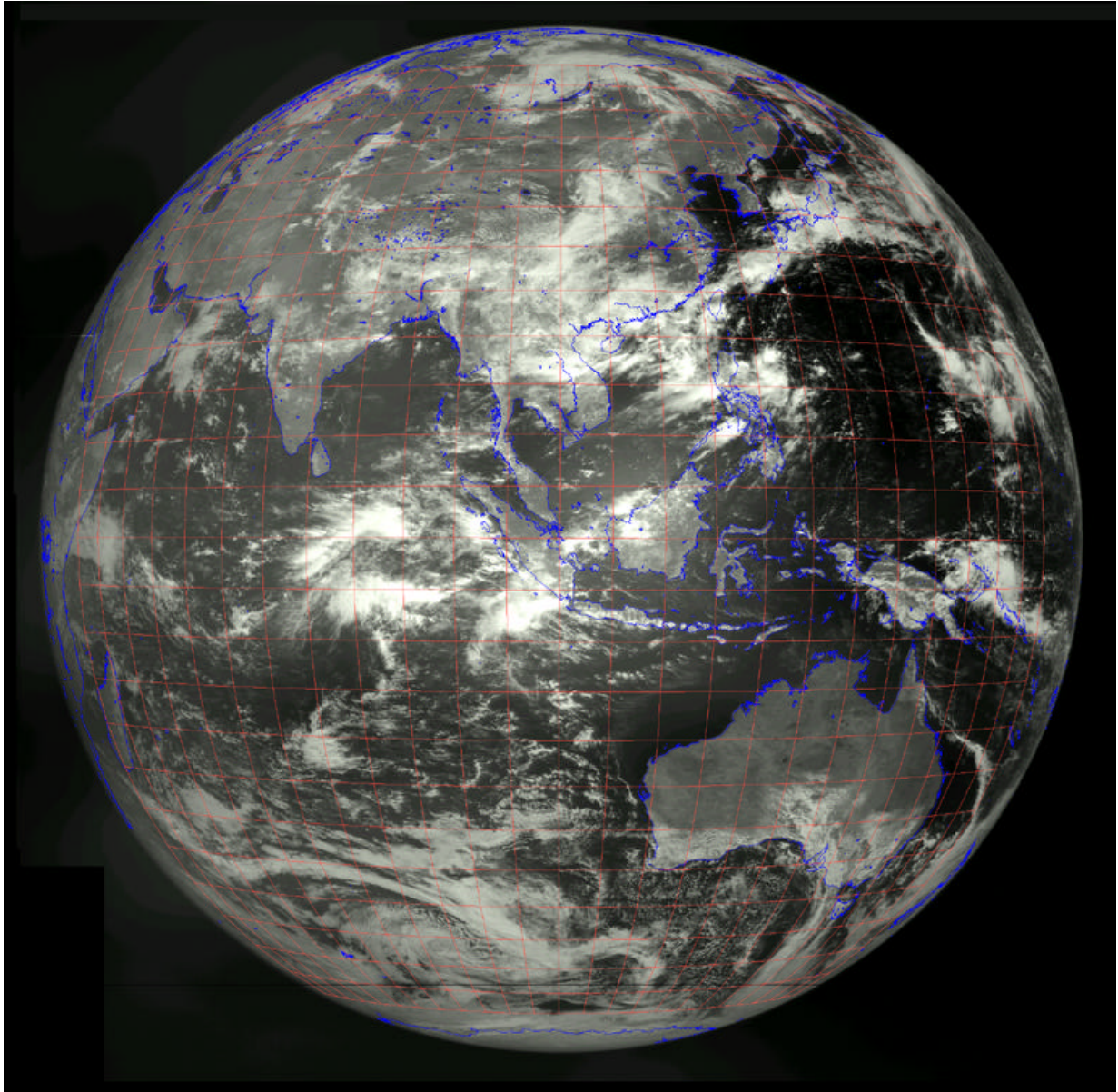


Figure 6. FY-2B navigation result

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