IMAGE COLLECTION PLANNING ALGORITHM FOR SINGLE PASS STEREO IMAGING

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ABSTRACT: The DEM (Digital Elevation Model) can be obtained from stereo image pair acquired by LEO satellite. Stereo images may consist of at least two images with different viewing angles to the imaging target for one pass or multiple passes. While each image is generally acquired from each pass in cross-track direction for multiple passes, stereo image pair in along-track direction can be acquired during one pass with attitude control capability for the pitch axis of the satellite. Single pass stereo imaging provides stereo pair image more efficiently on the fact that stereo pair image is generated with less orbit resources and less imaging time consumption. In this paper, the feasibility study result on the stereo pair image collection planning algorithm during single pass is addressed.

KEY WORDS: Stereo images, single pass, image collection planning, attitude control

1. INTRODUCTION

There have been many efforts to extract ground elevation using earth observation images from LEO satellite on sun-synchronous orbit. The SPOT series (1-4) have been successfully provided earth observation images of 10~20m resolution with the provision of stereo image pairs acquired in multiple passes. However, repeat cycle of the sun-synchronous orbit and cloud condition have limited the opportunity to get a complete stereo image pair in time and it led to the increase of the cost. Consequently, SPOT5 has been designed to acquire a stereo image pair through imaging in along-track direction in one pass.

The stereo image pair can be acquired conceptually in one time if the satellite system has the capability of attitude control, especially on the pitch axis. The operation concept for single pass stereo imaging provides efficiency considering that stereo pair image can be acquired with less orbit & time resources. In this paper, the feasibility study result on the stereo pair image collection planning algorithm in single pass is addressed.

2. PREREQUISITE CONDITION FOR SINGLE PASS STEREO IMAGING

Considering the single pass stereo imaging operation concept, a stereo image pair should be acquired in a single pass since the DEM can be generated from two images with difference viewing angle on the target area. It means that the satellite has the capability of changing the direction of Line Of Sight (LOS) to get 2nd image after getting 1st image on target area considering that the satellite passes near the target area with the velocity of few km/sec. In general, the change of LOS direction can be achieved through the attitude control system for payload or bus in many satellite systems. In the case of the satellite which has the attitude control system for the bus, the capability for controlling satellite attitude on the pitch axis is necessary since the single pass stereo imaging can not provide stereo image pair which is acquired in cross-track direction.

As a conclusion, the capability of attitude control on pitch axis in satellite system is the prerequisites to achieve single pass stereo imaging in the case of the satellite which has the attitude control system for the bus.

3. IMAGE COLLECTION PLANNING FOR SINGLE PASS STEREO IMAGING

Figure 1 shows the suggested operation concept for single pass stereo imaging in detail. In this chapter, the imaging collection planning algorithm for single pass stereo imaging is suggested in the case of the satellite which has the attitude control system for the bus only.

3.1 Assumption

It is assumed that the attitude reference frame of the satellite is the Local Vertical Local Horizontal (LVLH) frame. So, attitude control system is assumed to keep satellite's body axes in line with the attitude reference frame when stereo imaging is not performed. In addition, the direction of the LOS is assumed to be the same with the yaw axis of the satellite body axes.

3.2 Input Data

3.2.1 Target Position and Viewing Angle

To make the image collection plan for stereo image pair acquisition, the geographic position of target area and viewing angle applied to the target area, which are provided by the user, are to be acquired. Viewing angle actually defines the pitch tilt angle to be fed into the attitude control system.

3.2.2 Input : Predicted Satellite Position & Velocity

The predicted satellite position & velocity in Earth-Centered Earth-Fixed (ECEF) frame is to be used.

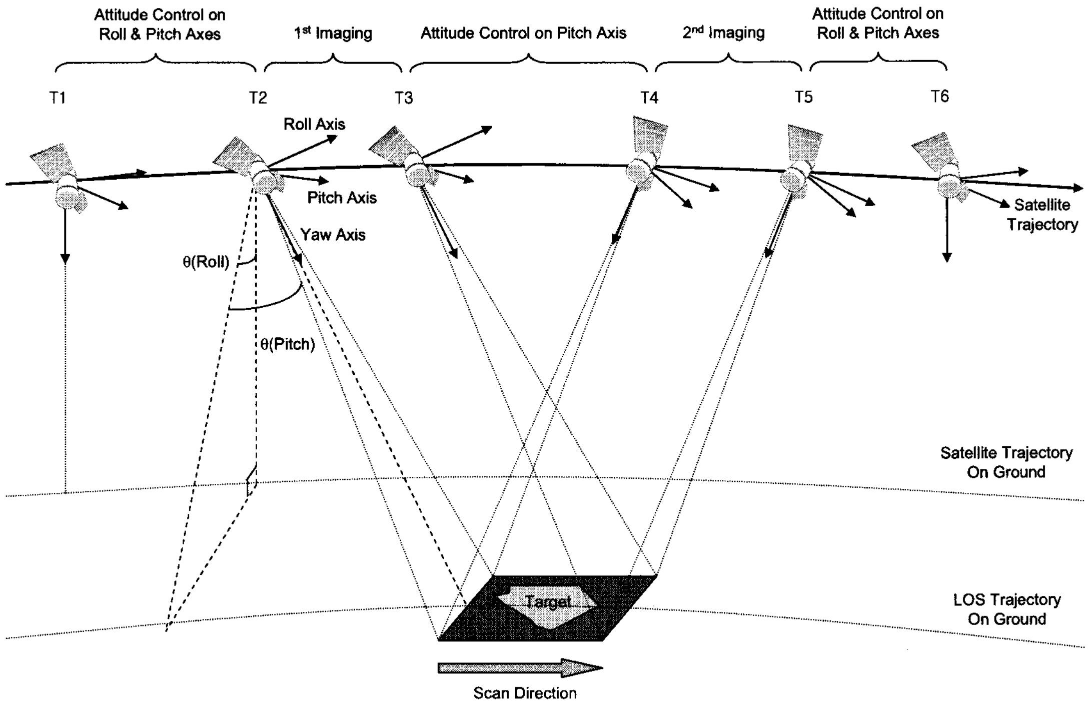

Figure 1. Operation Procedure for Single Pass Stereo Imaging

3.2.3 Input : Maneuver Time Needed for Attitude Control

A series of rotation around satellite's body axes is to be applied to point imaging target correctly for getting stereo image pair. It means that time for attitude control and stabilization is required to point imaging target without wobbling. It is assumed that information as followings are provided in advance before image collection planning for single pass stereo imaging.

- Expended time for Roll Maneuver including control and stabilization
- Expended time for Pitch Maneuver including control and stabilization

Consequently, attitude control and stabilization for rotation around roll and pitch axes have to be completed during time interval both between T1 and T2 and between T5 and T6 in Figure 1. Also, attitude control and stabilization for rotation around pitch axis has to be completed during time interval between T3 and T4.

3.3 Detailed Processing Steps of Image Collection Planning for Single Pass Stereo Imaging

Figure 2 shows detailed processing steps of image collection planning algorithm suggested for single pass stereo imaging.

3.3.1 Coordinates Transformation: ECEF=>LVLH

It is necessary to apply the rotation around pitch axis with required viewing angle to get the attitude in time T2 in Figure 2. To do this, the position of the satellite in LVLH frame has to be determined using the position and velocity of the satellite in ECEF frame via ECI frame.

3.3.1.1 Coordinates Transformation: ECEF=>ECI

The position & velocity of the satellite in ECI frame can be calculated according to the equation (1) & (2).

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{ECI} = \begin{pmatrix} \cos(\Omega\Delta t) & -\sin(\Omega\Delta t) & 0 \\ \sin(\Omega\Delta t) & \cos(\Omega\Delta t) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{ECEF} \quad (1)$$

$$\begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix}_{ECI} = \begin{pmatrix} \cos(\Omega\Delta t) & -\sin(\Omega\Delta t) & 0 \\ \sin(\Omega\Delta t) & \cos(\Omega\Delta t) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} v_x - \Omega \cdot y \\ v_y - \Omega \cdot x \\ v_z \end{pmatrix}_{ECEF} \quad (2)$$

Where Ω = Earth's rotation rate

Δt = Time difference of X axes between ECEF frame and ECI frame.

3.3.1.2 Coordinates Transformation: ECI=>LVLH

The position vector in LVLH frame can be calculated according to the equation (3), (4), (5) and (6).

$$\hat{z}_{LVLH} = -\frac{\vec{r}_{ECI}}{|\vec{r}_{ECI}|} \quad (3)$$

$$\hat{y}_{LVLH} = \frac{\vec{v}_{ECI} \times \vec{r}_{ECI}}{|\vec{v}_{ECI} \times \vec{r}_{ECI}|} \quad (4)$$

$$\hat{x}_{LVLH} = \hat{y}_{ECI} \times \hat{z}_{ECI} \quad (5)$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{LVLH} = (\hat{x}_{LVLH}, \hat{y}_{LVLH}, \hat{z}_{LVLH})^T \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{ECI} \quad (6)$$

Where $\vec{r}_{ECI} = (x, y, z)_{ECI}$, $\vec{v}_{ECI} = (v_x, v_y, v_z)_{ECI}$.

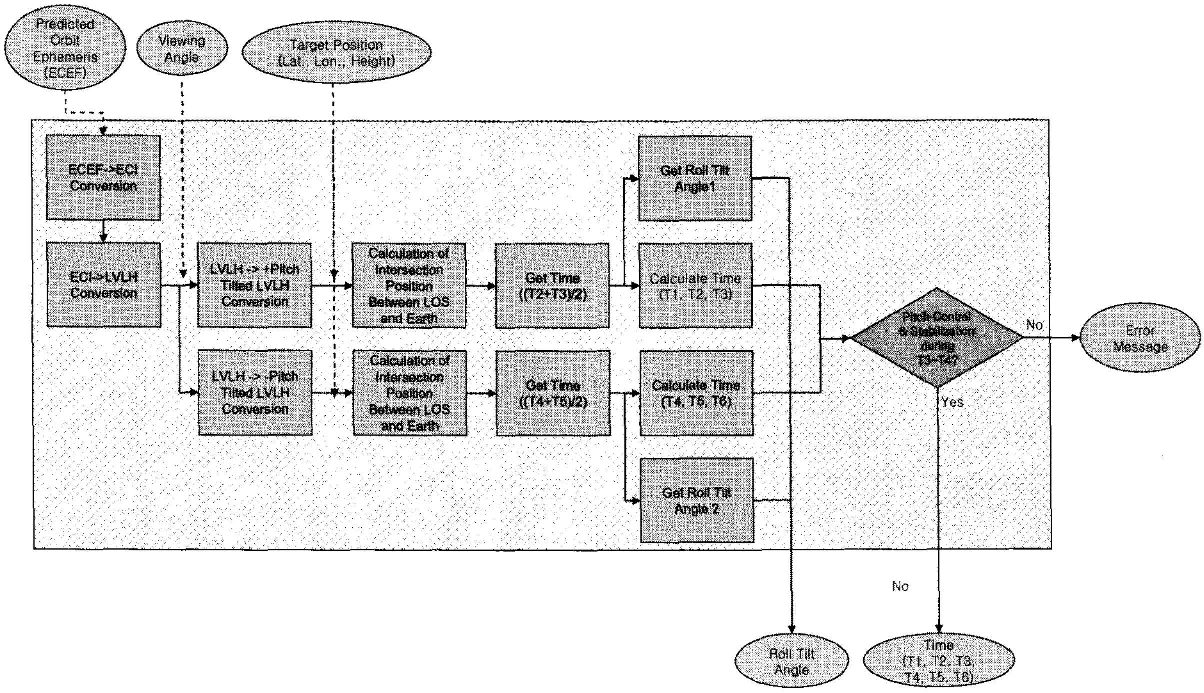

Figure 2. Image Collection Planning Algorithm for Single Pass Stereo Imaging

3.3.2 Rotation of LVLH frame with (+) Viewing Angle

The position of the satellite in new LVLH frame, LVLH' frame, which are acquired after rotation with (+) viewing angle has been applied, can be calculated according to the equation (7).

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{LVLH'} = \begin{pmatrix} \cos(\theta_v) & 0 & -\sin(\theta_v) \\ 0 & 1 & 0 \\ \sin(\theta_v) & 0 & \cos(\theta_v) \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{LVLH} \tag{7}$$

Finally, the vector $\overrightarrow{A_1O}$ in Figure 3 can be calculated after moving the origin of new LVLH frame from the Earth's center to the center of the satellite.

3.3.3 Determination of T2 & T3 with (+) Viewing Angle

Since the intersection point on ground, B_1, lies on the yaw axis, the vector $\overrightarrow{A_1B_1}$ for every time step can be acquired with following equation (8).

$$\overrightarrow{A_1B_1} = \left(0, 0, c - R_{pol} \cdot \sqrt{1 - \frac{a^2 + b^2}{R_{eq}^{\ 2}}} \right) \tag{8}$$

Where R_{eq} = Equatorial radius of the Earth

R_{pol} = polar radius of the Earth

(a,b,c) = the vector to the Earth's center in LVLH' frame of which center is located in the satellite.

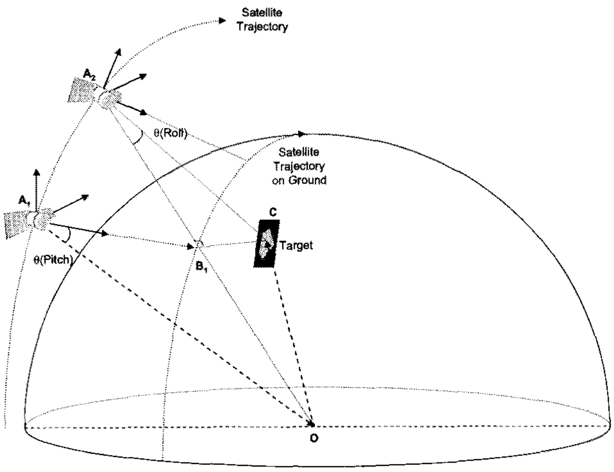

Figure 3. Geometry while Single Pass Stereo Imaging

Consequently, the B1, where the distance from the target is minimal, can be determined. This leads to the determination of the imaging time for the target, T^+. Finally, T2 and T3 can be acquired as equation (9) & (10).

$$T2 = T^+ - \Delta t^+ \tag{9}$$

$$T3 = T^+ + \Delta t^+ \tag{10}$$

Where Δt^+ = the half of the imaging time around target area with (+) viewing angle.

3.3.4 Determination of Roll Tilt Angle with (+) Viewing Angle

After getting the exact time T^+ in chapter 3.3.3, the rotation angle around roll axis, $\angle B_1A_2C$, can be calculated.

3.3.5 Determination of T1 with (+) Viewing Angle

After determining T2, T1 can be determined with the equation (11).

$$T1 = T2 - \Delta t^1 \quad (11)$$

Where Δt^1 = the time to be expended in the control and stabilization for rotation around roll & pitch axes to get the attitude in T2.

3.3.6 Rotation of LVLH frame with (-) Viewing Angle

The position vector of the satellite in new LVLH frame, LVLH' frame, which are acquired after rotation with (-) viewing angle has been applied, can be calculated according to the equation (7).

3.3.7 Determination of T4 & T5 with (-) Viewing Angle

With the same approach addressed in chapter 3.3.3, T^-, T4 andT5 can be acquired as equation (12) & (13).

$$T4 = T^- - \Delta t^- \quad (12)$$

$$T5 = T^- + \Delta t^- \quad (13)$$

Where T^- = the imaging time for the target with (-) viewing angle

Δt^+ = the half of the imaging time around target area with (-) viewing angle.

3.3.8 Determination of Roll Tilt Angle with (-) Viewing Angle

After getting the exact time T^- in chapter 3.3.7, the rotation angle around roll axis, $\angle B_1 A_2 C$, can be calculated. There may be a need for checking difference of roll tilt angles between the case of (+) and (-) viewing angles even though the difference is negligible during stereo imaging time interval.

3.3.9 Determination of T6 with (+) Viewing Angle

After determining T5, T6 can be determined with the equation (14).

$$T6 = T5 + \Delta t^2 \quad (14)$$

Where Δt^2 = Time to be expended in the control and stabilization for rotation around roll & pitch axes to get the attitude in T6.

3.3.10 Determination of T6 with (+) Viewing Angle

After determining T5, T6 can be determined with the equation (15).

$$T6 = T5 + \Delta t^2 \quad (15)$$

Where Δt^2 = Time to be expended in the control and stabilization for rotation around roll & pitch axes to get the attitude in T6.

3.3.11 Feasibility Check for Rotation around Pitch Axis between T3 and T4

Feasibility of rotation around pitch axis between T3 and T4 should be checked. If the attitude control and stabilization with rotation around pitch axis cannot be achieved during the interval between T3 and T4, it is concluded that the single pass stereo imaging with a given viewing angle is not possible.

3.4 Output Data

3.4.1 Feasibility Check Result : Pass

If the feasibility study shows that the rotation around pitch axis guarantee the attitude control and stabilization between T3 and T4, following data can be achieved.

Table 1. Output Data after Feasibility Check

Output	Description
T1	Start time for rotation around roll & pitch axes to get the 1st image of the stereo image pair
T2	Start time for the 1st imaging of the stereo image pair
T3	Stop time for the 1st imaging of the stereo image pair
T4	Start time for the 2nd imaging of the stereo image pair
T5	Stop time for the 2nd imaging of the stereo image pair
T6	Start time for rotation around roll & pitch axes to return to the nominal attitude in orbit
Roll Tilt Angle	Roll tilt angle to be applied for pointing target correctly

3.4.2 Feasibility Check Result : Failure

If the feasibility study shows that the rotation around pitch axis between T3 and T4 can not achieve the attitude control and stabilization, the error message has to be provided to the operator of image collection planning subsystem that single pass stereo imaging with a given viewing angle is not possible.

4. CONCLUSION

The result of feasibility study on the stereo pair image collection planning algorithm during single pass has been addressed.

In the view point of image collection planning, time series when attitude control and stabilization are to be performed and rotation angle around roll axis have to be determined. The result shows that these kinds of information can be determined in advance on ground. The algorithm presented in this paper can be applied to the image collection planning for single pass stereo imaging if the satellite has the capability of attitude control on satellite body axes in satellite system.