

Geometric correction model for dual sensor pushbroom aerial camera

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Abstract. Geometric correction is necessary in photogrammetry and remote sensing to avoid geometric distortions and establish relationship between image coordinate and its corresponding ground coordinate. Rigorous sensor model is one of the methods which considered the most precise and accurate for geometric correction. However, as rigorous sensor model contains many equations that depend on the actual physical properties of the sensor, the model is specialized for each sensor. In this paper, we modified a rigorous sensor model of geometric correction for pushbroom imager into geometric correction model for dual sensor pushbroom imager. The result shows that a model has been successfully obtained and can be used to geometrically correct coordinates of dual sensor pushbroom imagery.

1. Introduction

Geometric correction is necessary in photogrammetry and remote sensing to avoid geometric distortions and establish relationship between image coordinate and its corresponding ground coordinate [1]. Generally, there are two methods for geometric correction, namely rigorous sensor model [2] and rational function model [3]. Rigorous sensor model is a method in which a model is built based on the sensor's metadata such as borne position, velocity, and attitude angles [4]. Meanwhile, rational function model is based on rational polynomial coefficient provided by the vendor. Between those two, rigorous sensor model is one considered the most precise and accurate for geometric correction [5]. However, as rigorous sensor model contains many equations that depend on the actual physical properties of the sensor, the model is specialized for each sensor.

In this paper, we modified a rigorous sensor model of geometric correction for pushbroom imager into geometric correction model for duals sensor pushbroom imager. The result shows that a model has been successfully obtained and can be used to geometrically correct coordinates of dual sensor pushbroom imagery.

The paper is organized in the following way. Section 2 describes the pushbroom sensor. Section 3 explains the rigorous sensor model. Section 4 describes the methodology used in this paper. Section 5 shows our geometric correction model. Section 6 shows the validation results and discussion on the model. Lastly, the conclusions presented in Section 6.

2. Pushbroom Sensor

Pushbroom sensor is a lens system with linear array detector such as CCD and CMOS. Because the detector produce linear array, then the image created by it is only one line form considered one dimation (figure 1). Hence, two dimation image is obtained by slide the camera and taking one line by one line hundreds or thousands times [6].



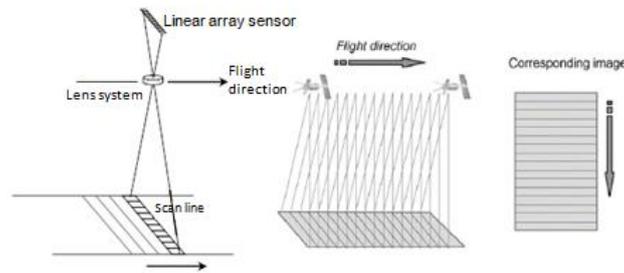


Figure 1. Illustration of how pushbroom sensor works

Linear array pushbroom scanners are characterized by their particularly distinct imaging principle and their diverse, complex physical structures in comparison with conventional frame cameras. That is, the image scenes are formed by stitching the one-dimensional scan lines captured as the sensor moves. On the other hand, it is almost impossible to rigorously define the epipolar geometry of linear pushbroom satellite imagery, primarily because the determination of the accurate geometric relationship between object space and image space is difficult due to the adopted multicenter projection imaging mode. [7]

Inderaku-2A is one of LAPAN's aircraft that carry two identical line scan camera (LQ200CL) and one still camera (NikonD800e). Each line scan camera is mounted 17.5 and -17.5 degree off the aircraft axis, respectively. Technical data for the line scan camera is presented in Table 1.

Table 1. Line scan camera technical data.

| Variable | Value | Unit |
|-------------------------|-------|--------|
| Pixel pitch | 0.014 | mm |
| Number of pixel | 2048 | pixel |
| Focal length | 35 | mm |
| Camera 1 rotating angle | 17.5 | degree |
| Camera 2 rotating angle | -17.5 | degree |

3. Rigorous Sensor Model

Rigorous Sensor Model (RSM) is a physical model that describe the imaging geometry and the transformation between the image coordinates and the terrestrial coordinates. RSM is established by restoring the look direction for each image pixel based on high accuracy data, such as the attitude and position of the satellite. Basic principle in RSM is that of collinearity, in which the exterior orientations of the sensor are directly and linearly affected by the interior orientation. In general, the RSM equation in collinearity equation is described in the following equation:

$$\begin{pmatrix} 0 \\ g_s \\ -f \end{pmatrix} = mR(t) \begin{pmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{pmatrix} \quad (1)$$

Where g_s denotes the y image coordinate of the sensor coordinate system with the origin at the perspective centre, the y -axis parallel to the array of the detectors and the z -axis perpendicular to the y -axis directed from the array towards the perspective centre. f denotes the focal length of the camera. m denotes the unknown scale factor. x, y, z denote the coordinates of the of the ground point. x_0, y_0, z_0 are the coordinates of the perspective centre of the camera. $R(t)$ is the rotational matrix to transform the coordinate from geocentric to sensor coordinate system. The satellite's position and rotation matrix are the exterior orientation, while the principle point and distance are interior orientation.

3.1. Sensor's internal orientation

Internal orientation consists of a set of parameters that allow us to transform image file pixels to the real physical dimensions of the image. These parameters are obtained from the camera characteristics, including focal length and principal point. These parameters allow us to transform the image coordinate within array scan line to the detector coordinate system.

Internal orientation on pushbroom imager is measured by mapping the pixel's location on the array scan line and identification of the camera's physical structure.

3.2. Sensor's external orientation

External orientation determines the exact position and orientation of the camera at the precise moment that the image was taken. It consists of the three-dimensional coordinate of the sensor's position, and the three rotations of the sensor's attitude.

4. Methodology

The general algorithm we developed to geometrically correct dual sensor pushbroom aerial camera is as follow:

1. Defining data input which consists of position and attitude of the pushbroom camera, number of line, number of pixel per line, pixel pitch, and focal length.
2. Converting position data from latitude, longitude, altitude (LLA) system into earth centred, earth fixed (ECEF) system.
3. Calculating the look direction vector of the camera for each pixel
4. Calculating the look direction vector of the instrument
5. Calculating the look direction vector of the body frame
6. Calculating the look direction vector of the local level frame
7. Calculating the look direction vector of the earth centred frame
8. Calculating the intersection vector point
9. Calculating the pixel position on earth
10. Converting the pixel coordinates back to LLA system

5. Geometric correction model

The general algorithm we developed to geometrically correct dual sensor pushbroom aerial camera is as follow:

1. Converting the GPS data from LLA to ECEF

Geodetic coordinates (latitude, longitude, height) can be converted into ECEF coordinates using the following equation:

$$X = (N(\phi) + h) \cos \phi \cos \lambda \quad (2)$$

$$Y = (N(\phi) + h) \cos \phi \sin \lambda \quad (3)$$

$$Z = \left(\frac{b^2}{a^2} N(\phi) + h \right) \sin \phi \quad (4)$$

$$N(\phi) = \frac{a^2}{\sqrt{(a \cos \phi)^2 + (b \sin \phi)^2}} \quad (5)$$

Where ϕ is latitude, λ is longitude, h is altitude, a (equatorial radius) = 6378.1370 km and b (polar radius) = 6356.7523 km. This radius of curvature in the prime vertical which is perpendicular to M at geodetic latitude ϕ is [g]. this radius is also called the transverse radius of curvature. At the equator, $N = R$.

2. Camera frame

The look direction for the camera frame is denoted by i_k and is defined as a relation between the pixel coordinate of the image and the detector coordinate system. The transformation relation is given by equation 6.

$$i_k = \begin{pmatrix} x_{ik} \\ y_{ik} \\ z_{ik} \end{pmatrix} = \begin{pmatrix} (\frac{N_p}{2} - n)p_x \\ 0 \\ -f \end{pmatrix} \quad (6)$$

Where N_p denotes number of pixel in a line, n denotes the pixel's number, p_x denotes pixel pitch, and f denotes focal length.

3. Instrument frame

The look direction for the instrument frame is denoted by i_a is defined by the following equation:

$$i_{a+} = \begin{pmatrix} x_{ia+} \\ y_{ia+} \\ z_{ia+} \end{pmatrix} = \begin{pmatrix} \cos \beta_1 & 0 & -\sin \beta_1 \\ 0 & 1 & 0 \\ \sin \beta_1 & 0 & \cos \beta_1 \end{pmatrix} \quad (7)$$

$$i_{a-} = \begin{pmatrix} x_{ia-} \\ y_{ia-} \\ z_{ia-} \end{pmatrix} = \begin{pmatrix} \cos \beta_2 & 0 & -\sin \beta_2 \\ 0 & 1 & 0 \\ \sin \beta_2 & 0 & \cos \beta_2 \end{pmatrix} \quad (8)$$

Where β_1 and β_2 denote the camera rotating angle for sensor 1 and sensor 2, respectively.

4. Body frame

Body frame is defined as body axis or camera axis, in which the axis center = body mass center + instrument

5. Local level frame

The local level used in this paper is defined as coordinate axis local east, local north, and local up, abbreviated as ENU. The central of the axis is the body mass center plus instrument. The transformation from body to local level frame is rotational, in accordance with the measurement of attitude sensor over time.

$$R_b^l = \begin{pmatrix} \cos y \cos r - \sin y \sin p \sin r & -\sin y \cos p & \cos y \sin r + \sin y \sin p \cos r \\ \sin y \cos r + \cos y \sin p \sin r & \cos y \cos p & \sin y \sin r - \cos y \sin p \cos r \\ -\cos p \sin r & \sin p & \cos p \cos r \end{pmatrix} \quad (9)$$

$$\begin{pmatrix} x^l \\ y^l \\ z^l \end{pmatrix} = R_b^l \begin{pmatrix} x^b \\ y^b \\ z^b \end{pmatrix} \quad (10)$$

Where p , y , and r denote the value of pitch, yaw, and roll respectively.

6. Centered earth frame

Centered earth framed, denoted by i_e is the center of the earth where the x axis is the straight line on equatorial plane from O toward longitude 0 (Greenwich), y axis is the straight line on equatorial plane from O and perpendicular to x axis, and z axis is the straight line on earth rotating axis, from O toward the north pole. Therefore, geometry from LLF frame to ECEF frame involves the LLA position from the vector that will be transformed, in this case, LLA position of the airborne used to carry the sensor.

$$R_l^e = \begin{pmatrix} -\sin \lambda & -\sin \varphi \cos \lambda & \cos \varphi \cos \lambda \\ \cos \lambda & -\sin \varphi \sin \lambda & \cos \varphi \sin \lambda \\ 0 & \cos \varphi & \sin \varphi \end{pmatrix} \quad (11)$$

$$\begin{pmatrix} x^e \\ y^e \\ z^e \end{pmatrix} = R_l^e \begin{pmatrix} x^l \\ y^l \\ z^l \end{pmatrix} \quad (12)$$

7. Earth intersection

After obtaining the look direction for centered earth frame, the next step is to find the intersection of satellite look direction within geocentric Cartesian coordinate using the following equation:

$$\left(\frac{(u_3)_x^2 + (u_3)_y^2}{A^2} + \frac{(u_3)_z^2}{B^2} \right) \mu^2 + 2 \left(\frac{x_p(u_3)_x + y_p(u_3)_y + z_p(u_3)_z}{A^2} + \frac{z_p(u_3)_z}{B^2} \right) \mu + \left(\frac{x_p^2}{A^2} + \frac{z_p^2}{B^2} \right) = 1 \quad (13)$$

8. Pixel position on earth

The position for each pixel on earth is calculated by the following equation:

$$\vec{g} = \vec{ap} + \mu i_e \quad (14)$$

Where \vec{ap} denotes the pixel position obtained using equation (2), (3), and (4), μ is scale factor obtained by solving equation (13), and i_e denotes the look direction calculated using equation (12).

9. Converting to LLA system

After that, we convert the coordinates back from ECEF coordinate system to LLA coordinate system using following equation:

$$\text{latitude} = \tan^{-1} \frac{z_g}{\sqrt{x_g^2 + y_g^2}} \quad (15)$$

$$\text{longitude} = \cos^{-1} \frac{x_g}{\sqrt{x_g^2 + y_g^2}} \quad (16)$$

6. Result and Discussion

A test were conducted to investigate whether the model we proposed is accurate. Five datasets of position and attitude of dual camera CMOS sensors were evaluated in this study. The data is shown in table 2.

Table 2. Five datasets of position and attitude of dual camera CMOS

| Number of Pixel | Yaw | Roll | Pitch | Latitude | Longitude | Altitude |
|-----------------|----------|-------|-------|----------|-----------|----------|
| 1 | -179.88 | 0.1 | 0 | -6.73343 | 108.1634 | 831.67 |
| 500 | -179.885 | 0.1 | 0 | -6.73643 | 108.1634 | 833.67 |
| 1024 | -179.885 | 0.125 | 0.1 | -6.73943 | 108.1634 | 838.67 |
| 1500 | -179.883 | 0.15 | 0 | -6.74243 | 108.1634 | 835.67 |
| 2048 | -179.88 | 0.11 | -0.1 | -6.74543 | 108.1634 | 835.67 |

The data above is corrected using the proposed mathematical model, and the result is presented in table 3.