The Globe Image Interpretation and Mapping

Yang Ming Hui  Ren Wei Chun
Chinese Academy of Surveying and Mapping
No16 Bei Tai Ping Road, Haidian district, Beijing, 100039, China
Tel: (86)-10-68222464, Fax: (86)-10-68218654
E-mail: yangmh@casm.ac.cn
E-mail: weichun@casm.ac.cn

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ABSTRACT: Globe Image collected by space borne and airborne EOS records a great quantity of spatial information concerning globe resources and environment which can be used to interpret the global change happened in short circle to help human being understanding the natural and social evolution. Advanced EOS is going on developing rapidly, From which the globe image can be processed and oriented almost in real time. The globe image collected in different time with different electronic magnetic waveband (microwave, infrared, visible spectrum, ultraviolet rays ) can be fused for interpretation, topographic and thematic mapping as well the further mapping on Internet to satisfy planning the sustainable development of human being society, economy and environment. Therefore, in this paper, the mathematic and physical expression of globe image taken by modern EOS, based on the fusion and visualization the interpretation and mapping are studied, and a planning Image Interpretation and Mapping Workstation prototype (I²M-1) is presented.

1 T-Collinear Equation Submitted

In modern satellite and aerial EOS, The sensor platform is always integrated with precise time measurement system, platform positioning and attitude measurement System . Considering the time-space relations among the platform, the moving vehicle and the earth (or other planet) physically, The T-collinear equation could be adopted for geometry processing of a globe image collected from advanced EOS.

T-Collinear Equation is the collinear equation correlative to time which means only at the instantaneous moment \( t_i \), the image point, projective center and object point on the ground are collinear and expressed as following:

\[
\begin{align*}
(X_2)_y &= X_{sl} + (\Delta X_i) + (h_y - Z_{si}) \frac{U_y}{W_y} \\
(Y_2)_y &= Y_{sl} + (\Delta Y_i) + (h_y - Z_{si}) \frac{V_y}{W_y} \\
t_i &= t_0 + lsp \cdot (l_i - l_0)
\end{align*}
\] (1)
In formula (1):

\[(X_2)_{ij}, (Y_2)_{ij}, (Z_2)_{ij}\] expresses the coordinates relative to navigation reference.

\(l_i\) the line containing the scene center

\(t_0\) the scene center time

\(l_{sp}\) the line sampling period

\[
\begin{bmatrix}
U_{ij} \\
V_{ij} \\
W_{ij}
\end{bmatrix} = R_{puk} \begin{bmatrix}
x_{ij} \\
y_{ij} \\
- f
\end{bmatrix}
\]

Or for Synthetic Aperture Radar imaging

\[
\begin{bmatrix}
U_{ij} \\
V_{ij} \\
W_{ij}
\end{bmatrix} = R_{puk} \begin{bmatrix}
\sqrt{R_y^2 \cos^2 \kappa - (h_{ij} - H_i)^2} & R_y \sin \kappa & (h_{ij} - H_i)
\end{bmatrix}
\]

Transformation matrix \( R_{puk} \) is the function of platform attitude in moment \( t_i \).

\[
\begin{align*}
\varphi_i &= (\varphi_0)_i + \Delta \varphi_i \\
\omega_i &= (\omega_0)_i + \Delta \omega_i \\
\kappa_i &= (\kappa_0)_i + \Delta \kappa_i
\end{align*}
\]

In the formula (4):

\[
\Delta \varphi_i, \Delta \omega_i, \Delta \kappa_i \quad \text{the relative attitude at time} \ t_i
\]

\[
(\varphi_0)_i, (\omega_0)_i, (\kappa_0)_i \quad \text{the correction of absolute attitude at time} \ t_i
\]

In case of precise ephemeris and enough sampling frequency adopted, the accuracy of dynamic platform positioning attained to decimeter even centimeter could be expected. The influence factor to accuracy is mainly the variation of absolute and relative attitude. The \((\Delta Y_i)\) and \((\Delta Y_i)\) in the formula are the components of time-space relation correction which deduces inversely and corrects the systematic errors caused by earth rotation, time delay and other errors in system integration.

2 Three dimension Registration and Fusion

2.1 Three dimension registration for globe image:

The registration of more than two scenes of globe image and the registration of globe image or stereo image pair with DEM or DSM covered same area mathematically are in the way of that projective transformation should be established between imaging space and earth space by means of the physical measurement parameters for image or stereo image pair and control points, for which the computing procedure is called as three dimension registration.
Three dimension registration for globe image is computed in uniform spatial rectangular reference, which could be the WGS 84 geocentric rectangular reference.

Based on each navigation reference, the satellite borne and airborne borne sensor collect the globe images. Starting from T-collinear equation, the observable equations for image or image pair could be established:

From left image:

\[
(X_{2k})_{ij} = (X_{2k})_{si} + (\Delta X)_{ijk} + ((Z_{2k})_{ij} - (Z_{2k})_{si}) \frac{U_y}{W_y} \\
(Y_{2k})_{ij} = (Y_{2k})_{u} + (\Delta Y)_{ijk} + ((Z_{2k})_{ij} - (Z_{2k})_{u}) \frac{V_y}{W_y} \\
\]

(5)

From right image:

\[
(X_{2k})'_{ij} = (X_{2k})'_{si} + (\Delta X)'_{ijk} + ((Z_{2k})'_{ij} - (Z_{2k})'_{si}) \frac{U_y'}{W_y'} \\
(Y_{2k})'_{ij} = (Y_{2k})'_{u} + (\Delta Y)'_{ijk} + ((Z_{2k})'_{ij} - (Z_{2k})'_{u}) \frac{V_y'}{W_y'} \\
\]

(6)

And

\[
(Y_{2k})'_{u} - (Y_{2k})_{si} + ((\Delta Y)'_{ijk} - (\Delta Y)_{ijk}) - ((Z_{2k})_{ui} \frac{V_y}{W_y} - (Z_{2k})_{ui} \frac{V_y'}{W_y'}) \\
(Z_{2k})_{ij} = \frac{(V_y - V_y')}{(W_y - W_y')} \\
\]

(7)
In formula (5), (6), (7), \((X_{2k})_y, (Y_{2k})_y, (Z_{2k})_y\) is the indirect observable for globe image or image pair, The code \(2k\) expresses that is relative to navigation reference \(k\). The indirect observable of the image or image pair covered same area can be transformed to WGS84 geocentric rectangular reference with formula (8):

\[
\begin{bmatrix}
(X_1)_y \\
(Y_1)_y \\
(Z_1)_y
\end{bmatrix} = (M_{21})_k \cdot \begin{bmatrix}
(X_{2k})_y \\
(Y_{2k})_y \\
(Z_{2k})_y
\end{bmatrix} + \begin{bmatrix}
(X_{1k})_0 \\
(Y_{1k})_0 \\
(Z_{1k})_0
\end{bmatrix}
\] (8)

In the formula (8): \((X_1)_y, (Y_1)_y, (Z_1)_y\) is the observable for uniform WGS 84 reference, \((M_{21})_k\) is the transformation matrix from navigation reference \(k\) to WGS84 reference and \((X_{1k})_0, (Y_{1k})_0, (Z_{1k})_0\) is the displacement constants.

2.2 Three dimension fusion for globe image

More than two scenes of globe image (including stereo image pair) superposed and displayed at the same time could be comparably interpreted, the procedure is called image fusion.

For image fusion, the spectral and spatial features for a pixel on globe image is expressed in linear space:

\[
\begin{bmatrix}
(A)_{rad} & 0 \\
(A)_{vis} & (A)_{mew} \\
0 & (A)_{spac}
\end{bmatrix} \ast \begin{bmatrix}
(x)_{rad} \\
(x)_{vis} \\
(x)_{mew} \\
(x)_{spac}
\end{bmatrix}
\] (9)

In formula, \((A)\) is a coefficient matrix, abbreviation rad vis mwv expresses respectively different electronic magnetic waveband.

\[
(x)_{spac} = \begin{bmatrix}
h \\
\Delta \tilde{H}
\end{bmatrix}
\] (10)

\(h\): The height relative to sea leveling

\(\Delta \tilde{H}\): The land cover depth

A globe image object is the textural distribution of pixels and expressed as matrix:

\[
(Y)_y = \begin{bmatrix}
(y_{11}) & (y_{12}) & \Lambda & (y_{1m}) \\
(y_{21}) & (y_{22}) & \Lambda & (y_{2m}) \\
\Lambda & \Lambda & \Lambda & \Lambda \\
(y_{n1}) & (y_{n2}) & \Lambda & (y_{nm})
\end{bmatrix}
\] (11)

The image information can be fused with different mode:
(1) Fusion of globe image with multi electronic magnetic band: Images collected by sensors with multi spectral band, microwave band and rays can be fused to interpret the physical and chemical features of a ground object.

(2) Fusion of globe image collected in different time: discovers the earth resources and environment changes caused by nature and human being activity as well the developing disaster sources.

(Figure 2 : A fused multi spectral stereo image pair)

(3) Fusion of globe image and geographic data: geographic data could be vector data, or vector data rasterized. After processing on GIS, the graphic data has been a spatial data set fused geographic and humanistic information which helps to interpret the semantic attribution of an image object.

Figure 2 is showing the multi spectral HRG image covered same area is fused with HRS stereo pair, and a fused multi spectral stereo image pair is generated.

3 Topographic Mapping and Thematic Mapping

Because of the requirement of the high resolution image mapping in large scale as well the topographic mapping and thematic mapping in mountain, the accuracy requirement of elevation measurement for DEM and DSM is correspondently raised. In modern satellite and aerial EOS technical system, The Synthetic Aperture Radar, Laser radar and stereo image pair are used for high accuracy phototopography.
Advanced satellite EOS takes attention to develop stereo image pair technology. In table 1, Two representative EOS satellites which can collect stereo image pair are presented.

Table 1:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Launch</th>
<th>Sensor</th>
<th>Waveband</th>
<th>Revolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOT5</td>
<td>2002/5/4</td>
<td>HRS</td>
<td>0.49-0.69μm</td>
<td>5/10 meters</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HRG</td>
<td>B1:0.50-0.59μm</td>
<td>2.5 meters</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B2:0.61-0.68μm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B3:0.79-0.89μm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SWIR:1.58-1.75μm</td>
<td></td>
</tr>
<tr>
<td>ALOS</td>
<td>2006/1/24</td>
<td>PRISM</td>
<td>0.52-0.77μm</td>
<td>2.5 meters</td>
</tr>
<tr>
<td>ALOS</td>
<td>2006/1/24</td>
<td>AVNIR-2</td>
<td>B1:0.42-0.50μm</td>
<td>10 meters</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B2:0.52-0.60μm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B3:0.61-0.69μm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B4:0.76-0.89μm</td>
<td></td>
</tr>
</tbody>
</table>

In case of satellite phototopography, seeing the formula (7), The instantaneous precise photographic base line can be determined. With a few control points on the ground, The time-space relation correction $\Delta X$, $\Delta Y$, the systematic errors correction from stellar observation/attitude measurement and other error sources can be deduced inversely. With formula (12), The accuracy of satellite phototopography is estimated:

\[
\begin{align*}
    m_x &= \sqrt{m_x^2 + \beta_z^2 m_z^2} \\
    m_y &= \sqrt{m_y^2 + \beta_z^2 m_z^2} \\
    m_z &= \beta_z \cdot \bar{m}_z
\end{align*}
\]

The mean square errors correspondence with one pixel resolution could be expected for satellite phototopography.

4 The Image Interpretation and Mapping Workstation

For image based topographic mapping, thematic mapping and further mapping on internet and web, The new prototype of image interpretation and mapping workstation should be developed in time.

(1) User activity and information sharing: Easily data access, searching, handling and sharing global image and relative geographic information on personal computer site are operated for popular globe image application; on other site, Easily image and graphic data compiling and basic mapping services …etc are operated for professional user.

(2) Image based topographic mapping and thematic mapping: Multi electronic magnetic band,
high resolution globe image and stereo image pair taken by modern EOS, Could be applied to topographic mapping, land use mapping, environment and disaster mapping, ocean and coast, tourist mapping and territorial security mapping.

(3) Image fusion and visualization: Image fusion and visualization should be the core for image interpretation and mapping workstation. With the image fusion, Not only the equivalent spectral resolution and equivalent spatial resolution are improved, The much more important is from different lateral face of the physical world, the features understanding of image object will be enhanced. From physical world to datum world, with visualization of globe or planet image from remote sensing and remote reconnaissance, the past, present and future world will be reconstructed. As Google Earth doing it reduces the temporal and spatial distance dramatically.
Figure 3a and 3b is showing the planning prototype of Image Interpretation and Mapping workstation.

Reference: