Comparative Analysis and Evaluation of Various Mathematical Models for Stereo IKONOS Satellite Images

by

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Presentation Outlines

Problem Definition

Need for Fast and Accurate Digital Terrain Model

- Stereo IKONOS Imagery: High Resolution Satellite Imagery Acquisition with Stereo Capability
- Photogrammetry Concepts: Mathematical Models applied to Stereo Satellite Images

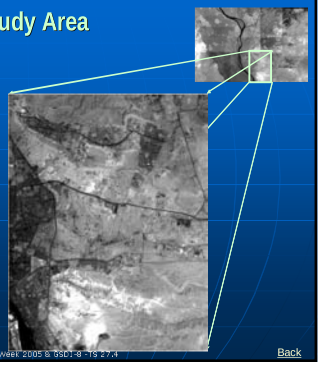
Objective and Methodology

Selection of the most suitable Mathematical Model for IKONOS Stereo images restitution.

- Acquiring stereo IKONOS satellite images for a study area.
- Studying the various mathematical models for IKONOS satellite stereo image restitution, and analyzing the specific requirements for each mathematical model by developing computer programs and using commercial software packages.
- Assessing the results of the different mathematical models based on high accurate ground control and check points.
- Studying the effect of the number and distribution of ground control points on the restitution results.

Study Area

- South-Eastern part of Cairo
- Area100 Km²
  Around 11.5km long by 8.5km width
- Various Topographic features.



Used Data and Programs

- Stereo Panchromatic IKONOS Image the first Stereo IKONOS in Egypt (Archive of Satellite Company)
- Satellite Ephemeris Data are not released, Imagery vendors supply RPC in Text File with the purchased Images.
- Ground Points collected by DGPS static technique.
- Commercial Software Packages:
  - PCI OrthoEngine, ERDAS OrthoBase, Intergraph Z/I Imaging SSK.
- Developed Computer Programs using MatLab

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Stereo IKONOS Images

Acquisition Date : 13 July 2003

Img_000

Elevation Angle : 71.51°
Azimuth Angle : 354 °

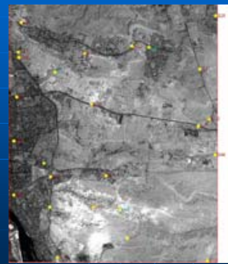
Img_001

Elevation Angle : 75.82°
Azimuth Angle : 219 °

B/H = 0.58

Ground Points

Total of Twenty-Five Ground Points are Collected by Static Differential GPS Technique to be used as ground Control and Check points.

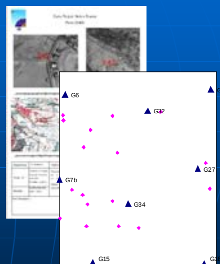


Experimental Work

- Data Preparation and Ground Points GPS Measurement
- Analysis and Evaluation of Satellite Images Sensor Modeling

Data Preparation and Ground Points Observation

- Pre-field work
  - Divide Study area with grid mesh
  - Choosing Point Location
- Field work
  - Verification of Point Locations
  - Observation by Static DGPS technique
- Post-field work
  - GPS Data Processing
  - Adjusting Network



Twenty-Five Distributed Ground Points are Collected

Satellite Images Sensor Modeling

- Comparative Analysis and Evaluation of various Mathematical Models for Satellite Images
  - Rational Function Model (RFM)
  - Refined Rational Function Model
  - 3D Affine Projection Model

Rational Function Model

- RFM for Single Images (PCI OrthoEngine Software)

$$x=\frac{a_0+a_1X+a_2Y+a_3Z+a_4X^2+a_5XY+a_6XZ+\ldots+a_{17}Z^2X+a_{18}Z^2Y+a_{19}Z^3}{b_0+b_1X+b_2Y+b_3Z+b_4X^2+b_5XY+b_6XZ+\ldots+b_{17}Z^2X+b_{18}Z^2Y+b_{19}Z^3}$$

$$y=\frac{c_0+c_1X+c_2Y+c_3Z+c_4X^2+c_5XY+c_6XZ+\ldots+c_{17}Z^2X+c_{18}Z^2Y+c_{19}Z^3}{d_0+d_1X+d_2Y+d_3Z+d_4X^2+d_5XY+d_6XZ+\ldots+d_{17}Z^2X+d_{18}Z^2Y+d_{19}Z^3}$$

- RFM for Stereo Images (ERDAS OrthoBase and Z/I Imaging SSK)

$$x=\frac{a_0+a_1X+a_2Y+a_3Z+a_4X^2+a_5XY+a_6XZ+\ldots+a_{17}Z^2X+a_{18}Z^2Y+a_{19}Z^3}{b_0+b_1X+b_2Y+b_3Z+b_4X^2+b_5XY+b_6XZ+\ldots+b_{17}Z^2X+b_{18}Z^2Y+b_{19}Z^3}$$

$$y=\frac{c_0+c_1X+c_2Y+c_3Z+c_4X^2+c_5XY+c_6XZ+\ldots+c_{17}Z^2X+c_{18}Z^2Y++c_{19}Z^3}{d_0+d_1X+d_2Y+d_3Z+d_4X^2+d_5XY+d_6XZ+\ldots+d_{17}Z^2X+d_{18}Z^2Y++d_{19}Z^3}$$

$$x'=\frac{e_0+e_1X+e_2Y+e_3Z+e_4X^2+e_5XY+e_6XZ+\ldots+e_{17}Z^2X+e_{18}Z^2Y+e_{19}Z^3}{f_0+f_1X+f_2Y+f_3Z+f_4X^2+f_5XY+f_6XZ+\ldots+f_{17}Z^2X+f_{18}Z^2Y+f_{19}Z^3}$$

$$y'=\frac{g_0+g_1X+g_2Y+g_3Z+g_4X^2+g_5XY+g_6XZ+\ldots+g_{17}Z^2X+g_{18}Z^2Y+g_{19}Z^3}{h_0+h_1X+h_2Y+h_3Z+h_4X^2+h_5XY+h_6XZ+\ldots+h_{17}Z^2X+h_{18}Z^2Y+h_{19}Z^3}$$

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RFM Model for Single Images

- Rational Polynomial Coefficients (80 Parameters) supplied by imagery vendors

Without GCPs

RMSE in meters for
17 CPs (No GCPs)

Image 000			Image 001		
X	Y	XY	X	Y	XY
1.32	8.26	5.91	2.68	4.13	3.48

Continue….

RFM Model for Stereo Images

- Rational Function Model using RPCs supplied with Image files

Without GCPs

RMSE in meters for
17 CPs (No GCPs)

Software	X	Y	XY	Z
ERDAS OrthoBase	2.67	3.39	3.05	6.88
Z/I Imaging SSK	3.53	3.69	3.61	5.97

Compatibles with results announced by satellite company(*Space Imaging May 2003*)

Refined Rational Function Model

Modeling accuracy will be improved when using GCPs in the RFM model

$$x + a_0 + a_1 x + a_2 y = \frac{F_1(X,Y,Z)}{F_2(X,Y,Z)}$$

$$y + b_0 + b_1 x + b_2 y = \frac{F_3(X,Y,Z)}{F_4(X,Y,Z)}$$

x and *y* — image coordinates,

F_i — third-order polynomial functions of object space coordinates *X*, *Y* and *Z*,

a_i and b_i — coefficients of Affine transformation.

Refined RFM Model for Single Images

- Using GCPs

With GCPs

8 GCPs / 17 CPs						20 GCPs / 5 CPs					
Image 000			Image 001			Image 000			Image 001		
X	Y	XY	X	Y	XY	X	Y	XY	X	Y	XY
1.59	1.83	1.71	1.58	0.96	1.31	1.51	1.29	1.40	1.44	0.98	1.23

Refined RFM Model for Stereo Images

- Using GCPs

Z/I Imaging SSK

	No GCPs / 17 CPs				1 GCPs / 17 CPs				2 GCPs / 17 CPs				4 GCPs / 17 CPs			
	X	Y	XY	Z	X	Y	XY	Z	X	Y	XY	Z	X	Y	XY	Z
RMSE	3.53	3.69	3.61	5.97	0.82	1.25	1.06	1.72	0.71	1.32	1.06	1.71	0.76	1.29	1.14	1.83

Bias Removing

Continue….

3D Mathematical Models for Stereo Images

- Using GCPs

ERDAS OrthoBase

	0 GCPs / 17 CPs				1 GCPs / 17 CPs				2 GCPs / 17 CPs				4 GCPs / 17 CPs			
	X	Y	XY	Z	X	Y	XY	Z	X	Y	XY	Z	X	Y	XY	Z
RMSE	2.67	3.39	3.05	6.88	1.18	1.11	1.14	2.09	1.10	1.12	1.11	2.07	1.09	1.31	1.21	1.93

Bias Removing

RPC Model Bias

- Differences between calculated coordinates without GCPs and with any number of GCPs.
- Mainly there is a SHIFT (Bias) in the results of the RPC Model.

Point_Id	dX (m)	dY (m)	dZ (m)
G10	-5.24	5.25	-8.22
G11	-5.24	5.25	-8.22
G12	-5.23	5.26	-8.21
G19	-5.23	5.28	-8.21
G3	-5.25	5.21	-8.23
G33	-5.24	5.34	-8.21
G35	-5.23	5.23	-8.22
G36	-5.25	5.21	-8.23
G37	-5.24	5.23	-8.22
G38	-5.24	5.26	-8.22
G40	-5.24	5.27	-8.21
G42	-5.25	5.24	-8.22
G43	-5.25	5.25	-8.22
G44	-5.24	5.35	-8.21
G45	-5.23	5.30	-8.21
G8	-5.25	5.29	-8.22
G8b	-5.24	5.24	-8.22

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3D Affine Projection Models

- For Single Image

$$x = a_0 + a_1X + a_2Y + a_3Z$$
$$y = b_0 + b_1X + b_2Y + b_3Z$$

  - Using a Developed Least Squares Computer Program (2 equations per point - 8 unknowns)

- For Stereo Images

$$x = a_0 + a_1X + a_2Y + a_3Z$$
$$y = b_0 + b_1X + b_2Y + b_3Z$$
$$x' = c_0 + c_1X + c_2Y + c_3Z$$
$$y' = d_0 + d_1X + d_2Y + d_3Z$$

  - Using a Developed Least Squares Computer Program (4 equations per point – 16 unknowns)

Continue….

3D Affine Projection Model for Single Images

- Using different number of GCPs

8 GCPs 17 CPs						20 GCPs 5 CPs					
Image 000			Image 001			Image 000			Image 001		
X	Y	XY	X	Y	XY	X	Y	XY	X	Y	XY
1.70	1.52	1.61	2.14	0.94	1.65	1.21	0.95	1.09	1. 60	0.91	1.30

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3D Affine Projection Model for Stereo Images

- Using different number of GCPs

8 GCPs / 17 CPs				12 GCPs / 13 CPs				16 GCPs / 9 CPs				20 GCPs / 5 CPs			
X	Y	XY	Z	X	Y	XY	Z	X	Y	XY	Z	X	Y	XY	Z
1.54	1.05	1.31	2.51	1.45	0.77	1.16	2.58	1.10	0.89	1.00	1.70	1.05	0.72	0.90	1.29

This model is greatly affected by number, distribution and accuracy of GCPs

Justification

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Justification of 3D Affine Sensor Modeling

"However, these models are appropriate only for cases in which perspective and elevation effects are small, such as satellite imagery or vertical mapping photography over flat terrain"

Reference:

"Digital Photogrammetry: an addendum to the Manual of Photogrammetry", ASPRS (1996)

These models : 3D affine Projection Model

IKONOS Satellite : Very high with small FOV

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Conclusions

- Sub-meter accuracy in X and Y and 1.5-2m in Z can be achieved for Stereo IKONOS imagery restitution process using two mathematical models (RFM and 3D Affine Projection).
- RFM Model is straight forward, however, it requires commercial software packages that support RPCs files.
- RFM Model is sensor independent and supports non-iterative solution for the real time restitution, and it can be used for stereo IKONOS orientation without GCPs.

Conclusions

- RFM Model provides more accurate results when refined by Bias/shift Removing (bias-compensated RFM) using One GCP only.
- 3D Affine Projection Model provides slightly more accurate results, however it is greatly affected by the number, distribution and quality of GCPs.

Conclusions

- 3D Affine Projection Model was found to be the most suitable model for users with unavailable photogrammetry commercial software.
- Refined RFM is the most suitable model for users with available photogrammetry commercial software which utilizes RPCs, since it requires ONE control point only.

Recommendations

- Study Relief-Corrected 3D Affine Projection Model (projection of GCPs on a reference height plane), similar to Orthorectified image generation technique for a single image.
- Development of Rigorous Mathematical Models for other Stereo High resolution satellite images with available camera parameters information, such as QuickBird, and comparison with RPF and 3D Affine Models.
- Comparative analysis between different sources for DSM/DTM generation (Aerial photos, High/Medium/Low Resolution Satellite images, Laser scanning, Radar images, Ground surveying) versus the required accuracy of the flood extent prediction, with respect to accuracy, availability, cost, speed, and area coverage.

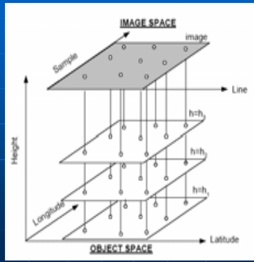
Thank You

RPC Text Files

LINE_NUM_C_1	7.06E-04	LINE_DEN_C_1	1.00E+00	SAMP_NUM_C_1	1.61E-03	SAMP_DEN_C_1	1.00E+00
LINE_NUM_C_2	1.46E-02	LINE_DEN_C_2	2.16E-03	SAMP_NUM_C_2	9.88E-01	SAMP_DEN_C_2	2.16E-03
LINE_NUM_C_3	-1.00E+00	LINE_DEN_C_3	6.41E-03	SAMP_NUM_C_3	1.46E-02	SAMP_DEN_C_3	6.41E-03
LINE_NUM_C_4	1.67E-02	LINE_DEN_C_4	-1.32E-03	SAMP_NUM_C_4	1.66E-03	SAMP_DEN_C_4	-1.32E-03
LINE_NUM_C_5	-2.06E-03	LINE_DEN_C_5	4.63E-06	SAMP_NUM_C_5	5.83E-03	SAMP_DEN_C_5	4.63E-06
LINE_NUM_C_6	3.11E-05	LINE_DEN_C_6	-3.89E-06	SAMP_NUM_C_6	-8.16E-04	SAMP_DEN_C_6	-3.89E-06
LINE_NUM_C_7	1.50E-03	LINE_DEN_C_7	4.38E-06	SAMP_NUM_C_7	-1.39E-04	SAMP_DEN_C_7	4.38E-06
LINE_NUM_C_8	-2.37E-04	LINE_DEN_C_8	8.99E-06	SAMP_NUM_C_8	2.13E-03	SAMP_DEN_C_8	8.99E-06
LINE_NUM_C_9	-6.44E-03	LINE_DEN_C_9	-2.16E-05	SAMP_NUM_C_9	1.06E-04	SAMP_DEN_C_9	-2.16E-05
LINE_NUM_C_10	-2.40E-05	LINE_DEN_C_10	3.72E-06	SAMP_NUM_C_10	8.29E-07	SAMP_DEN_C_10	3.72E-06
LINE_NUM_C_11	3.78E-06	LINE_DEN_C_11	-3.31E-09	SAMP_NUM_C_11	7.66E-06	SAMP_DEN_C_11	-3.31E-09
LINE_NUM_C_12	-4.38E-07	LINE_DEN_C_12	-1.01E-09	SAMP_NUM_C_12	8.96E-06	SAMP_DEN_C_12	-1.01E-09
LINE_NUM_C_13	-4.89E-06	LINE_DEN_C_13	1.24E-09	SAMP_NUM_C_13	-2.52E-05	SAMP_DEN_C_13	1.24E-09
LINE_NUM_C_14	-2.60E-08	LINE_DEN_C_14	1.08E-09	SAMP_NUM_C_14	3.25E-06	SAMP_DEN_C_14	1.08E-09
LINE_NUM_C_15	-1.09E-05	LINE_DEN_C_15	4.54E-09	SAMP_NUM_C_15	3.52E-06	SAMP_DEN_C_15	4.54E-09
LINE_NUM_C_16	2.17E-05	LINE_DEN_C_16	-5.90E-09	SAMP_NUM_C_16	-2.42E-07	SAMP_DEN_C_16	-5.90E-09
LINE_NUM_C_17	-3.77E-06	LINE_DEN_C_17	-1.13E-09	SAMP_NUM_C_17	2.04E-07	SAMP_DEN_C_17	-1.13E-09
LINE_NUM_C_18	-1.02E-06	LINE_DEN_C_18	-7.23E-09	SAMP_NUM_C_18	-2.41E-06	SAMP_DEN_C_18	-7.23E-09
LINE_NUM_C_19	-4.48E-06	LINE_DEN_C_19	1.48E-08	SAMP_NUM_C_19	-7.63E-07	SAMP_DEN_C_19	1.48E-08
LINE_NUM_C_20	6.48E-08	LINE_DEN_C_20	-6.47E-10	SAMP_NUM_C_20	3.30E-09	SAMP_DEN_C_20	-6.47E-10

Generation of RPCs

- RPC Estimation
  - A least-squares approach was utilized to determine the RPC model coefficients a_i, b_i, c_i and d_i from a 3-D grid of points generated using the physical IKONOS camera model.
  - The 3-D grid of object points was generated by intersecting the rays emanating from a 2-D grid of image points – computed using the physical IKONOS camera model – with a number of constant elevation planes.



3D Affine Projection

$x = a_0 + a_1X + a_2Y + a_3Z$
$y = b_0 + b_1X + b_2Y + b_3Z$

a0, a1, …, b3 : Parameters describing
(3) rotation
(2) translation
(3) non-uniform scaling and skew distortion

This equation can be interpreted as a 3D affine transformation followed by an orthogonal projection *(Yamakawa and Fraser, 2004)*

3D Mathematical Models for Stereo Images

- Rational Polynomial Function
  - To be calculated using GCPs

Requires Large Number of GCPs *40 GCPs*

Min. No of GCPs	6	20	40
No. of Parameters	12	40	80
Remarks	1st order RPF	2nd order RPF	3rd order RPF

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