Optimizing the Digital Processing Workflow Using Direct Georeferencing

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Outline

- **Overview**
- **Data Flow**
- **Quality Control**

Applanix Corporation

Applanix Today

- Head Office - 100 people, Richmond Hill, Ontario
- World Renowned in-house expertise in GPS/Inertial Technology
- Global operations: offices in USA, Germany, and UK, with agents worldwide
- Over **600 POS systems sold** -> **300+ POS AV** systems
- Created the market of using GPS/inertial for aerial surveys in 1994
- A Subsidiary of Trimble Navigation

POS System Evolution

1986 - 1991

→

1996 - 2003

2004

Direct Georeferencing Systems in Survey Practice

Inertial Measurement Unit IMU

Real Time Computer System with embedded GPS receiver and Data Logger

Leica ALS 50

Top-RMK Mount

RC30 Mount

Embedded IMU in Z/I DMC

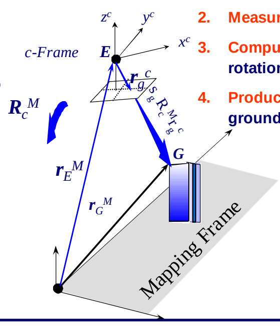
Embedded IMU in LHS ADS 40

Optech ALTM

What is Image Georeferencing

Direct Georeferencing

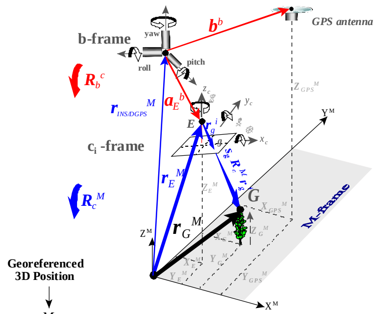
1. **Measure translation and rotation (EO) using Navigation Sensors**
2. **Produce Orthophoto or collect features on stereopairs**
3. **No GCP needed**
4. **QC is needed**



Indirect Georeferencing

1. **Survey GCPs**
2. **Measure image points**
3. **Compute translation and rotation using AT**
4. **Produce 3D Coordinates of ground Points**

Direct Image Georeferencing



$$r_G^M = r_{INS/DGPS}^M(t) + R_b^M(t)\; a_E^b \;+\; s_g \; R_b^M(t)\; R_c^b \; r_g^c(t)$$

IMU/GPS — IMU — Calibration — Stereopair Processing — IMU — Calibration By GCP — Image Measurement and Camera Calibration

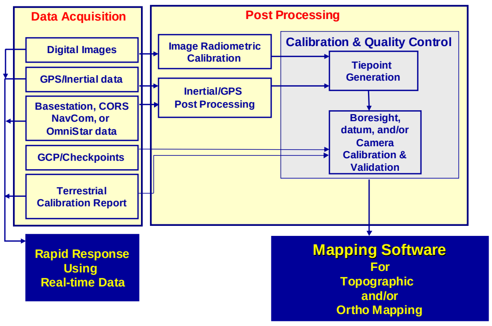
The Digital Sensor System (DSS)

Complete Mapping System

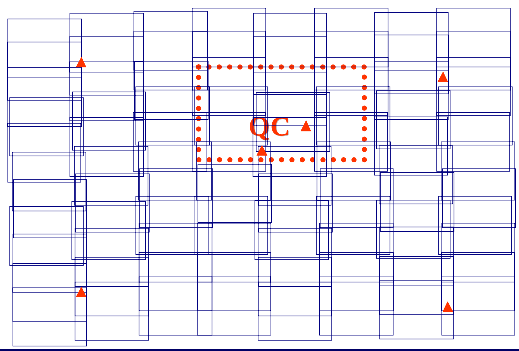
- turn-key
- fully-digital
- medium format

- Built-in FMS
- Integrated POS AV Aided Inertia Direct Georeferencing System
- 4k by 4k Color and CIR Digital Imager
- Azimuth Mount (*new*)
- Ruggedized data logger and pressurized drive

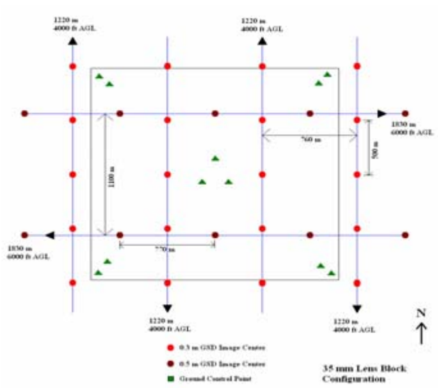
The DSS Data Flow



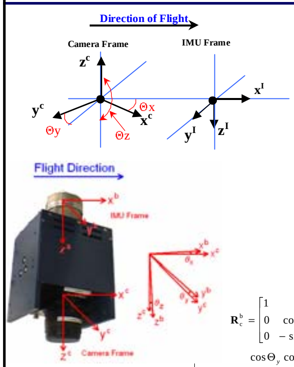
Airborne Calibration and Quality Control



Airborne Calibration and Quality Control



Boresight Calibration



- Boresight is the physical mounting angles of an IMU w.r.t. a camera
- Boresight is assumed constant matrix at all times
- Boresight is computed using:
  - Image rotation matrix computed by photogrammetry
  - IMU-derived rotation matrix
- How well the imaging geometry is established (camera calibration?)
- Correlation between the camera calibration and boresight ???
- This necessitates the simultaneous calibration of boresight and camera

$$\mathbf{R}_c^b = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Theta_x & \sin\Theta_x \\ 0 & -\sin\Theta_x & \cos\Theta_x \end{bmatrix} \begin{bmatrix} \cos\Theta_y & 0 & -\sin\Theta_y \\ 0 & 1 & 0 \\ \sin\Theta_y & 0 & \cos\Theta_y \end{bmatrix} \begin{bmatrix} \cos\Theta_z & \sin\Theta_z & 0 \\ -\sin\Theta_z & \cos\Theta_z & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\Theta_y\cos\Theta_z & \cos\Theta_y\sin\Theta_z & -\sin\Theta_y \\ \sin\Theta_x\sin\Theta_y\cos\Theta_z - \cos\Theta_x\sin\Theta_z & \sin\Theta_x\sin\Theta_y\sin\Theta_z + \cos\Theta_x\cos\Theta_z & \sin\Theta_x\cos\Theta_y \\ \cos\Theta_x\sin\Theta_y\cos\Theta_z + \sin\Theta_x\sin\Theta_z & \cos\Theta_x\sin\Theta_y\sin\Theta_z - \sin\Theta_x\cos\Theta_z & \cos\Theta_x\cos\Theta_y \end{bmatrix}$$

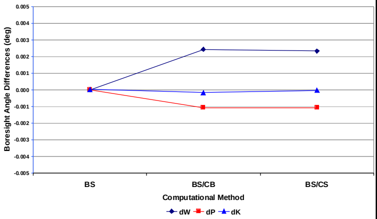
Effect of GCP on Boresight Calibration

The plot shows the difference between boresight calibration *with and without GCPs* for three different configurations:

- Boresight Calibration
- Boresight Calibration + Camera calibration
- Boresight Calibration + Camera Calibration for each strip

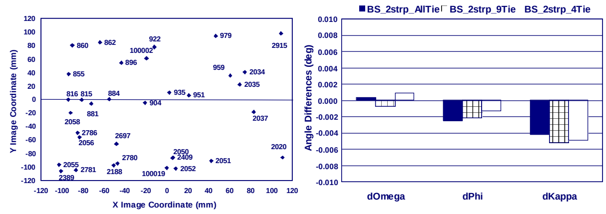
Difference in calibrated boresight angles is within POS/AV 510 used in the OEEPE project

- Δ Omega ~ 0.001 deg
- Δ Phi ~ 0.003 deg
- Δ kappa ~ 0.0 deg

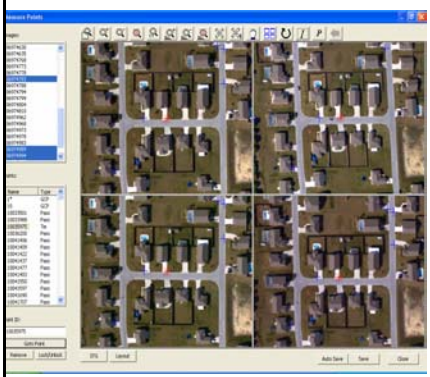


Effect of Number of Image Points

- Boresight calibration has been done three times
  1. Using all available photo measurements (left plot)
  2. Using only Von Gruber Points (9 per photo)
  3. Using only 4 points per photo
- Results of boresight calibration have been compared (right plot)
- Difference in boresight is within the POS/AV 510 system specs



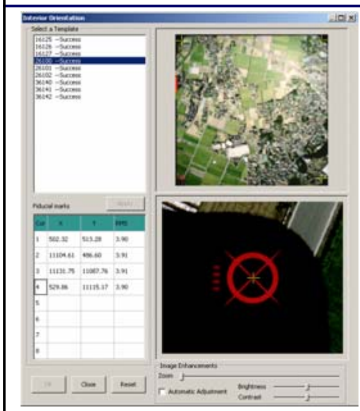
Airborne Calibration and Quality Control software



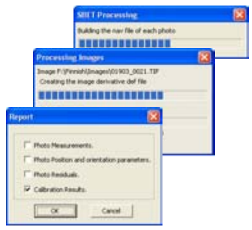
Calibration & Quality Control Software is equipped with:

- Online Calibration of boresight, camera, and datum
- Imports
  1. image coordinates from any AAT software
  2. POS Data
- Generates its own tie points using STG (semi-automatic Tiepoint Generation) Engine

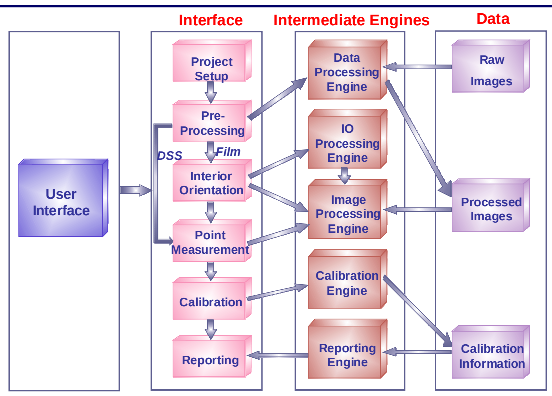
Airborne Calibration and Quality Control - Auto IO



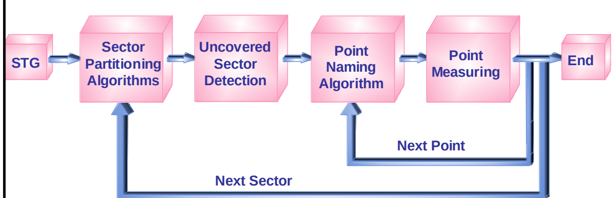
- Software Tools Work for:
  - Digital Camera
  - Scanned Film



Work Flow Design - CalQC



Semi-Automatic Tiepoint Generation (STG)



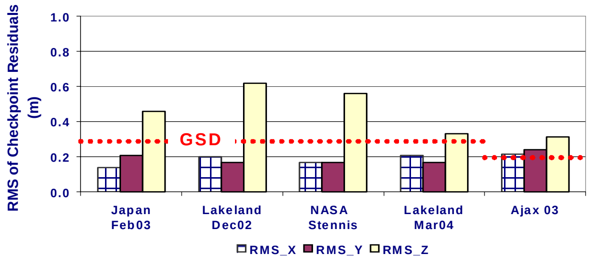
The DSS Performance

- The Performance of the DSS is discussed using results from five test flights

Flight ID	Flight Altitude AGL (m)	GSD (m)	#Strips/Photos	# Checkpoints
Lakeland Dec02	2000	0.3	6/65	37
NASA Stennis	2000	0.3	12/242	96
Japan Feb03	1300-1900	0.2-0.3	5/41	60
Ajax 03	1200	0.2	9/165	46
PASCO Toyonaka	300	0.05	6/150	16

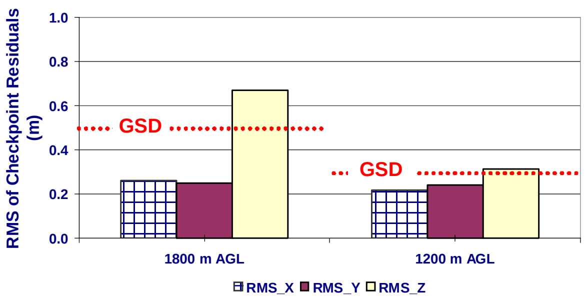
Statistical Summary of Different Test Flights

- Accuracy of Checkpoints is repeatable - sub-pixel in horizontal and 2-3 pixels in elevation (Geometry)



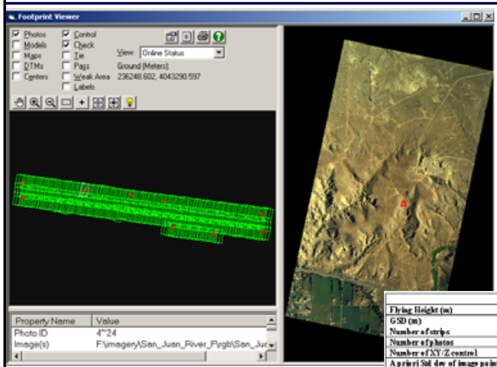
Statistical Summary of Different Test Flights

- Same results are repeatedly achieved using a 35 mm lens



Georeferencing The DMC Images Using POS

Georeferencing The DMC Images – An Example

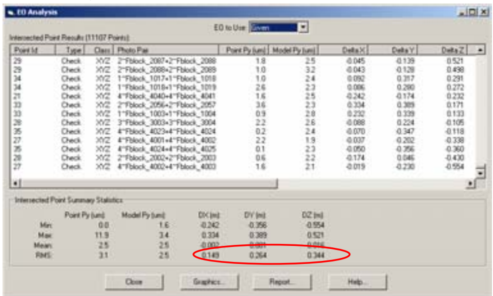


	Block F	F-Strip
Flying Height (m)	2,600	2,600
GSD (m)	0.25	0.25
Number of strips	4	1
Number of photos	287	89
Number of XY/Z control	8/9	4/5
Apriori Std dev of image point (um)	5	5
Apriori Std dev of control (m)	0.1	0.1
Apriori Std dev of GPS (m)	0.2	0.2
Apriori Std dev of INS (deg)	0.1	0.1

Madani, M., M.M.R. Mostafa, 2004. Georeferencing the DMC Images - Data Flow and Performance Analysis. Proceedings, ASPRS Annual Conference, Denver, CO, May 22-28. CD-ROM

Georeferencing The DMC Images – Results

- Remaining Errors are well within the GSD
- Remaining Errors include POS errors, image measurement errors, calibration errors, etc..



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Thank you for your attention!