Surveying Technology in Light Geometry

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- **Education:**
  - BS & MS in Civil Engineering, National Chung Hsing University, Taiwan
  - PhD in Civil & Environmental Engineering (Geomatics), University of Wisconsin-Madison, Wisconsin, USA (1994)
- **Teaching:**
  - Undergraduate: Surveying, Photogrammetry, Remote Sensing, Introduction to GIS, MATLAB programming
  - Graduate: Analytical Photogrammetry, Digital Image Processing, GIS, Digital Cartography
- **Research Interests:**
  - Technology in Photogrammetry, Remote Sensing, GIS

I. Introduction

- **Surveying (Geomatics)** has traditionally been regarded as the discipline which encompasses all methods for measuring, processing, and disseminating information about the physical earth and our environment (Ghilani & Wolf, 2016).
- **Definition of a surveyor**: a professional person with the academic qualifications and technical expertise to practice the science of measurements; to assemble and assess land and geographic related information; … (FIG, 1991).
- **Measurements in Surveying**: horizontal and vertical distances, angles, coordinates of feature points in image space, dense grids of coordinated points computed from combining distance and angle, and location information from satellite positioning.

- Surveying (Geomatics) has been a focal point of evolution in technology joining mathematical applications to innovations in mechanical engineering and instrument construction technology (De Graeve, 2010).

Light Geometry

- **Physical phenomenon:**

  Light, or electromagnetic radiation (EMR), travels through a transmitting medium in straight lines with a constant speed.

- **Geometric conditions ⇨ Mathematical equations**
  - Ground Surveying: **Visibility/Intervisibility**

    Occupied station ⬄ Target
  - Photogrammetry & Remote Sensing: **Collinearity condition**

    Ground feature ⇨ optical exposure center ⇨ image pixel
  - Satellite Positioning: **Visibility of satellites from receiver**

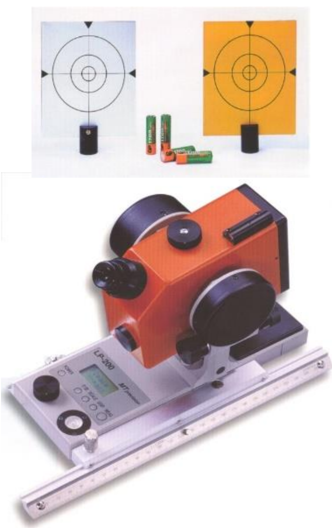
    Satellite (signal) ⇨ Receiver (Airplane/UAV/Car/Ground)
  - Active Sensors (SAR/LiDAR/Terrestrial Laser Scanner/EDM):

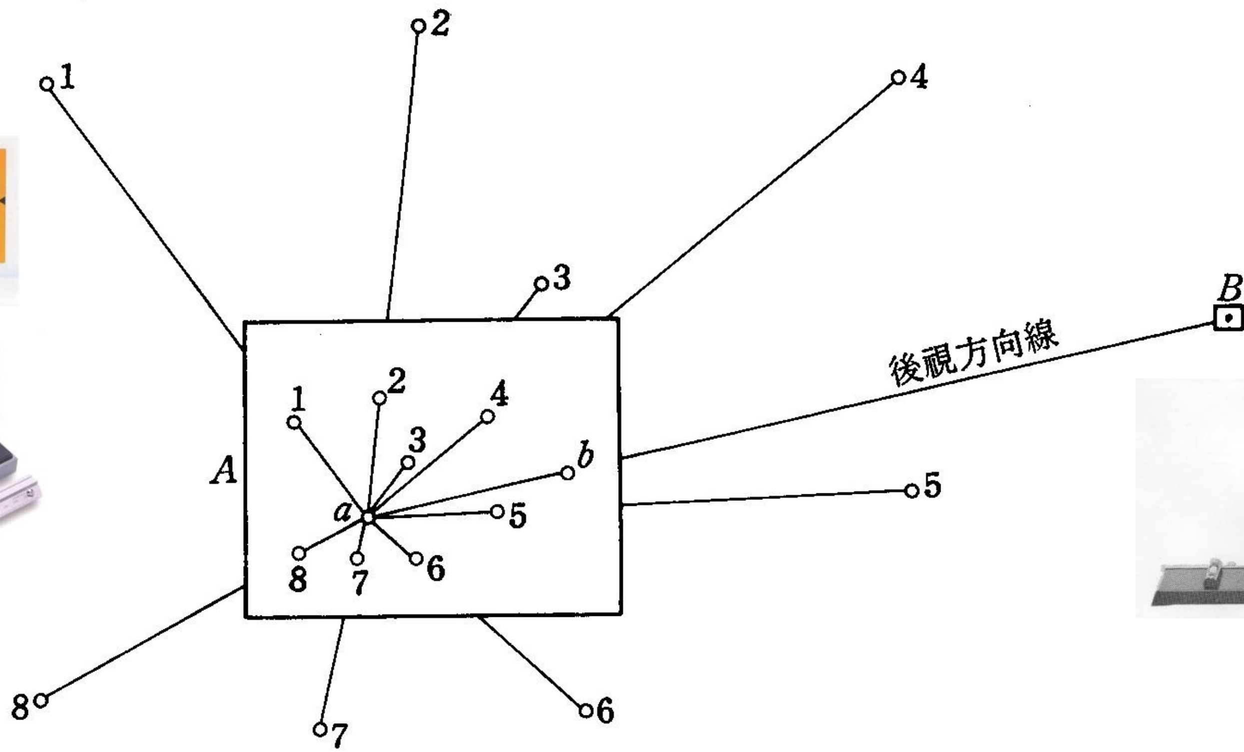
    Transmitter ⇨ Ground feature ⇨ Receiver

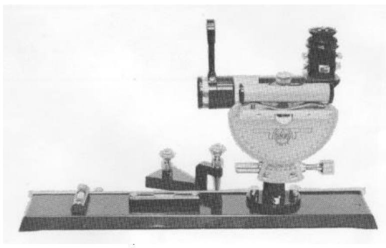
II. Review on Traditional Surveying

II.1 Alidade

- **Radiation:** known occupied station A and backsight station B







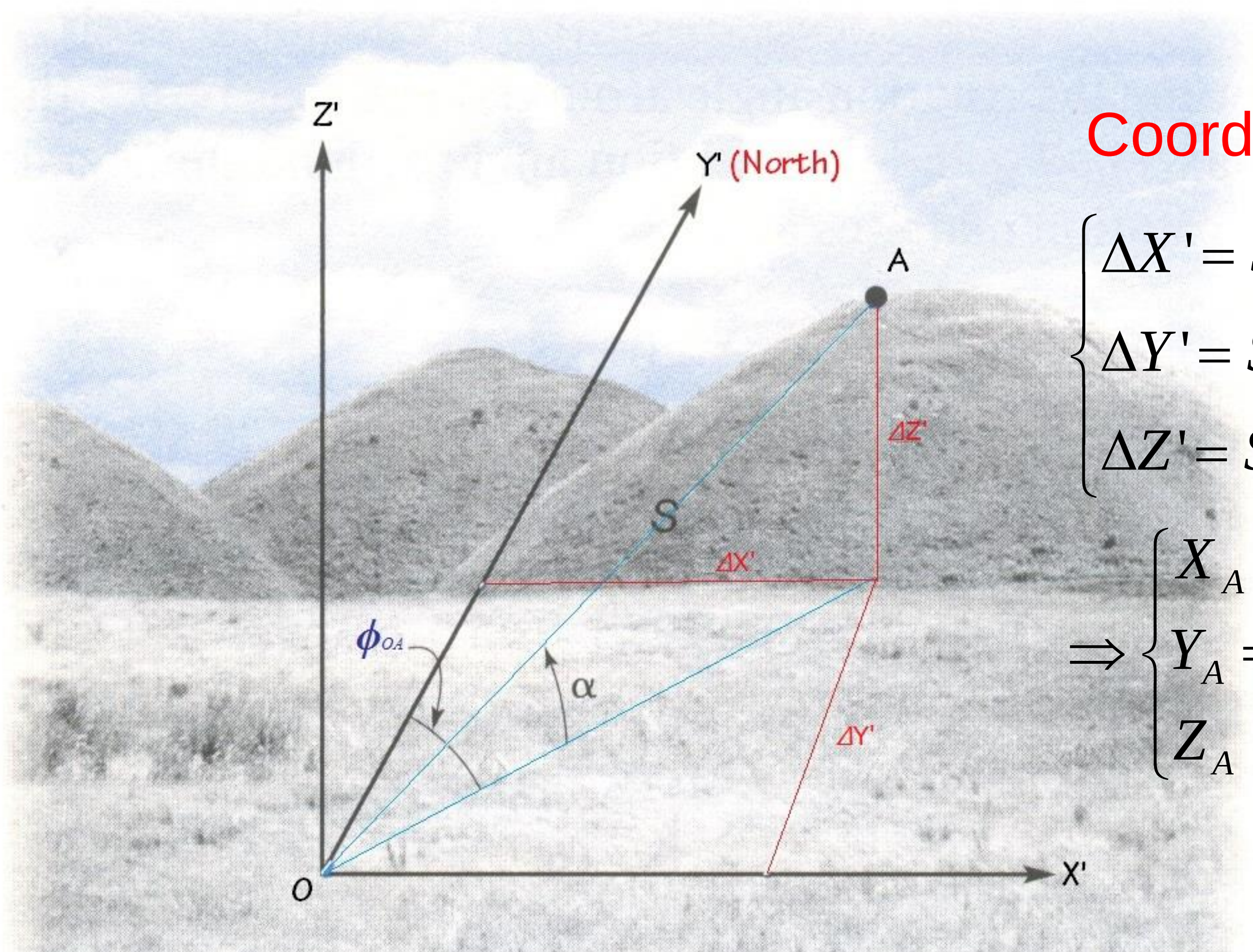
II.2 Total Station & Terrestrial Laser Scanner

- **Radial Traversing:**

1. Settle Total Station at known station O（X_O, Y_O, Z_O)
2. Backsight known control station Z, and set the horizontal angle the same as the azimuth of $\phi_{\overrightarrow{OZ}}$
3. Observe ground points A, B, C,…, and measure the slope distance (S), horizontal angle (ϕ), and vertical angle (α)
4. Compute coordinates of each observed point as (COGO):

$$\begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} = \begin{bmatrix} X_O \\ Y_O \\ Z_O \end{bmatrix} + S_{\overline{OA}} \times \begin{bmatrix} \cos\alpha_{\overrightarrow{OA}} \times \sin\phi_{\overrightarrow{OA}} \\ \cos\alpha_{\overrightarrow{OA}} \times \cos\phi_{\overrightarrow{OA}} \\ \sin\alpha_{\overrightarrow{OA}} \end{bmatrix}$$

Reduction of Observations in a Local 3-D Vertical Coordinate System



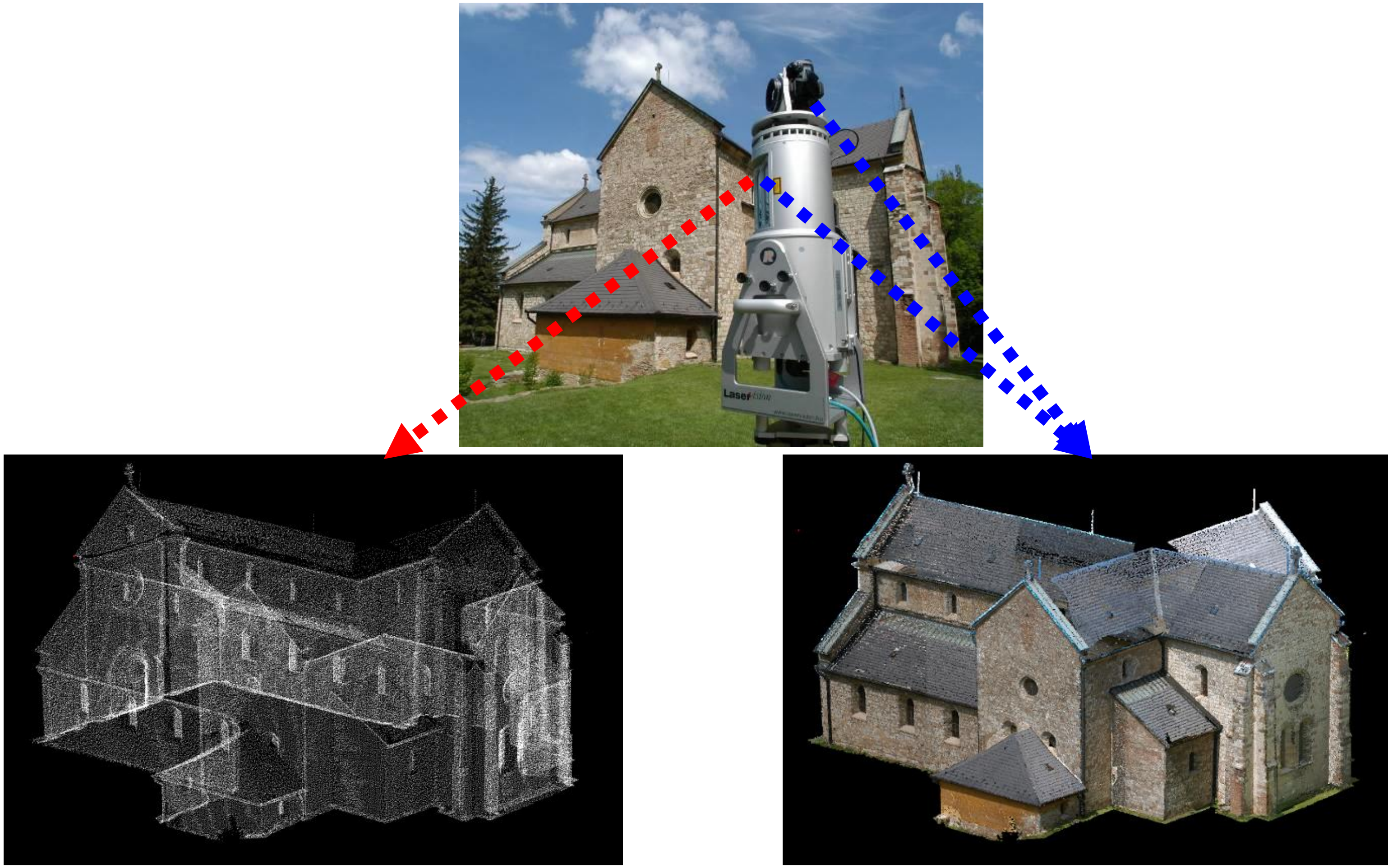
(after Ghilani & Wolf, 2016)

Coordinate Geometry:

$$\begin{cases} \Delta X' = S_{\overline{OA}} \times \cos \alpha_{\overrightarrow{OA}} \times \sin \phi_{\overrightarrow{OA}} \\ \Delta Y' = S_{\overline{OA}} \times \cos \alpha_{\overrightarrow{OA}} \times \cos \phi_{\overrightarrow{OA}} \\ \Delta Z' = S_{\overline{OA}} \times \sin \alpha_{\overrightarrow{OA}} \end{cases}$$

$$\Rightarrow \begin{cases} X_A = X_O + \Delta X' \\ Y_A = Y_O + \Delta Y' \\ Z_A = Z_O + \Delta Z' \end{cases}$$

3D Reconstruction from Point Cloud by Laser Scanner



Point cloud only

Composite of color image & point cloud

(Tseng，2010)

II.3 Intersection

In plane surveying, determining the point of intersection from two known control stations includes the following three situations (Ghilani & Wolf, 2016):

(1)Direction-direction problem: finding the intersection of two lines, each with respective azimuth of measured direction.

(2)Direction-distance problem: finding the intersection of a line (direction) with a circle with the radius of measured distance.

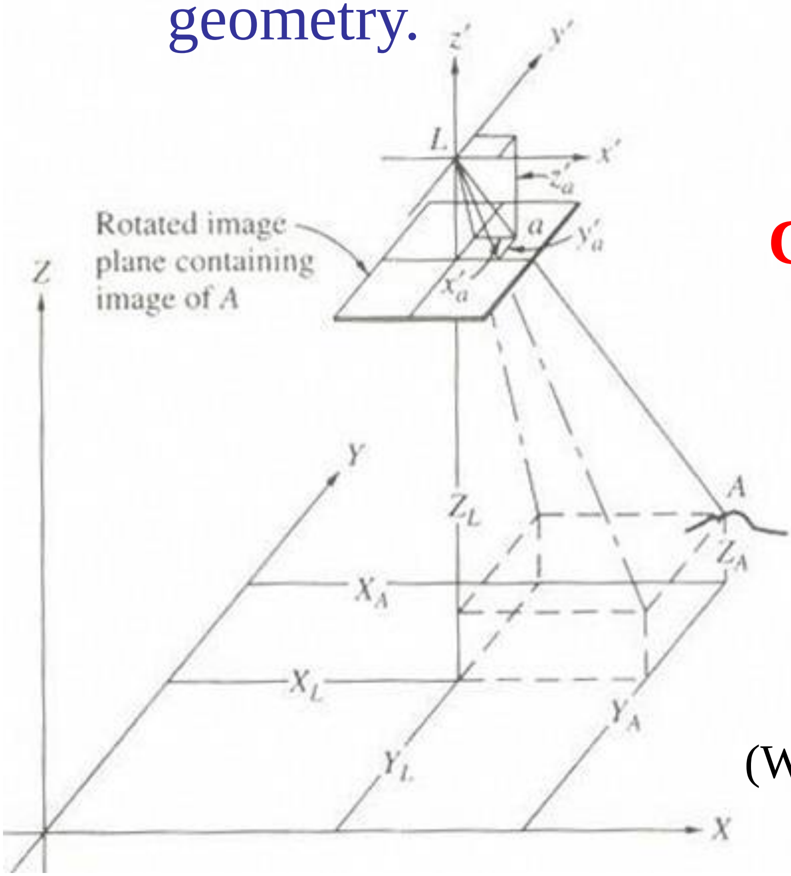
(3)Distance-distance problem: finding the intersection of two circles, each with respective radius of measured distance.

II.4 Resection

1. In plane surveying, the *three-point resection* locates a point of unknown position by observing horizontal angles from that point, where a total station instrument occupies, to three visible control points whose positions are known (Ghilani & Wolf, 2016).
2. In satellite positioning, the positioning principle in GPS is conceptually equivalent to 3-D *resection* of distances or *trilateration* in traditional ground surveying work (Ghilani & Wolf, 2016). The visibility condition between the ground stations becomes unnecessary because the observations in GPS surveying are the signals transmitted from the satellites on space orbits.

II.5 Aerotriangulation in Photogrammetry

The formation of pictorial photographs and digital images in photogrammetry and remote sensing is forced to the light geometry.

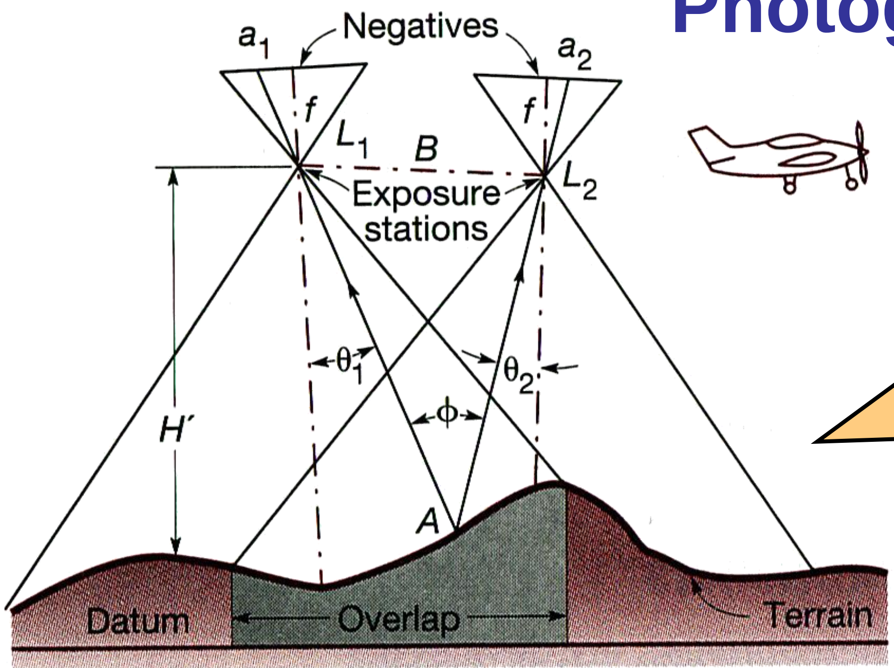


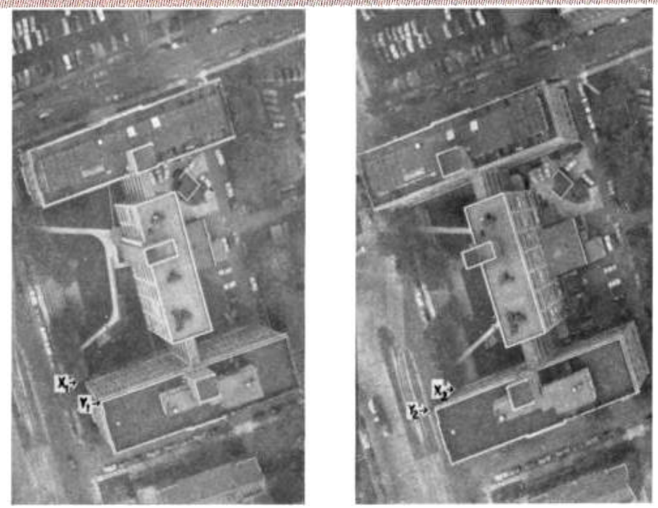
Collinearity Condition Equations：

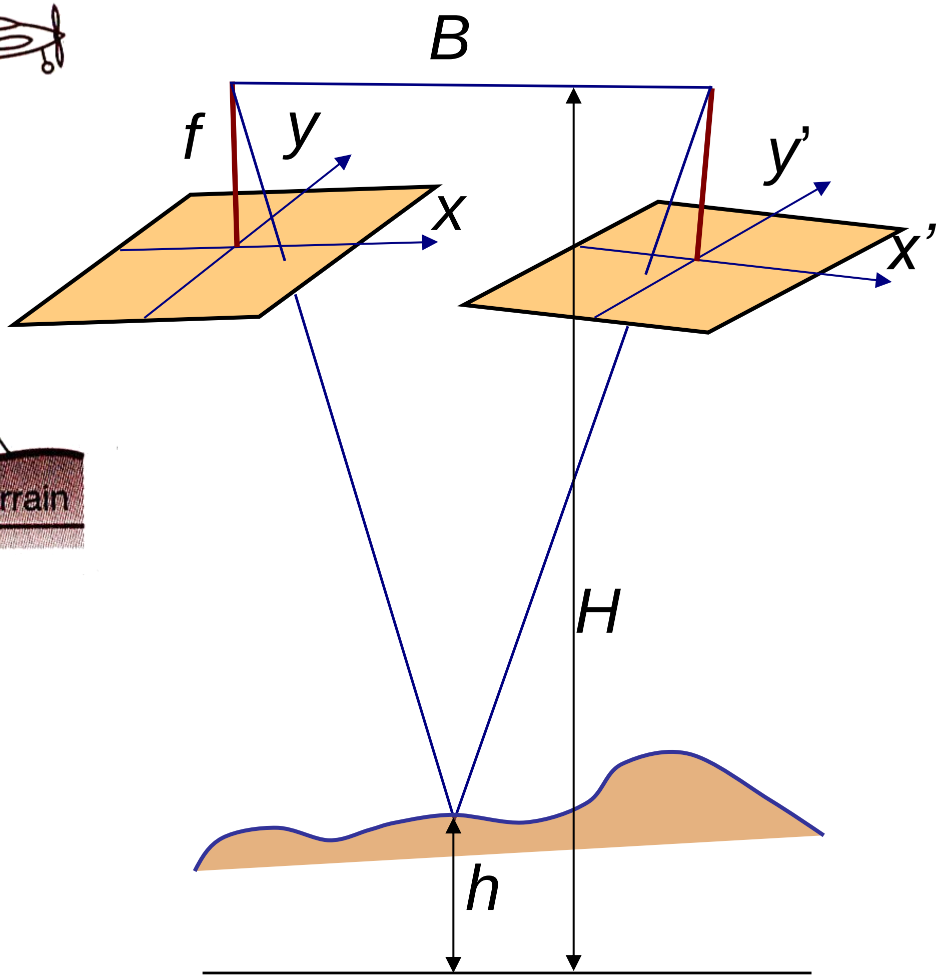
$$
\begin{cases}
x - x_0 = -f\left[\dfrac{m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)}\right] \\
y - y_0 = -f\left[\dfrac{m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)}\right]
\end{cases}
$$

(Wolf *et al.*, 2014)

Photogrammetric Mapping







(After Tseng, 2016)

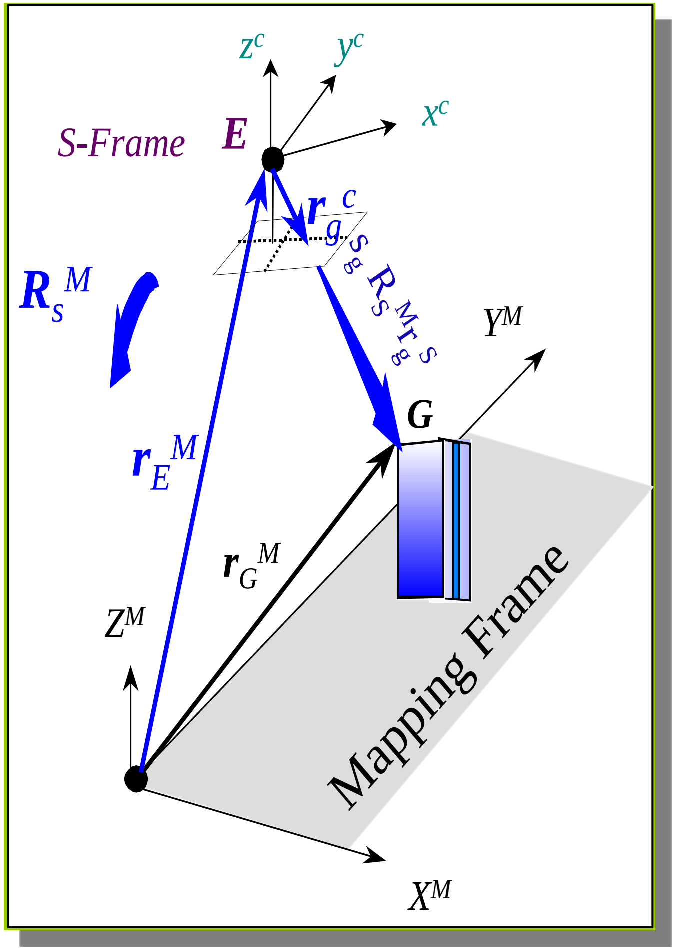
Photogrammetric Processes

- *space resection*: determine the exterior orientation parameters of photos from known control ground points;
- *space intersection*: determine the ground coordinates of object points within the overlapped coverage of a stereopair with known orientation parameters;
- *relative* orientation: determine the position and attitude relationship between the two images in a stereo pair;
- *absolute orientation*: determine the relation from the stereo model to the ground space;
- *block bundle adjustment*: solve for the unknown orientation parameters of all images and ground coordinates of all measured object points in a simultaneous solution.

III. Direct Georeferencing

What is a Direct Georeferencing system?

- It provides the ability to geo-reference the data collected by an imaging sensor/scanner to the Earth by measuring geographic position and orientation of the sensor, without the use of ground-based measurements.

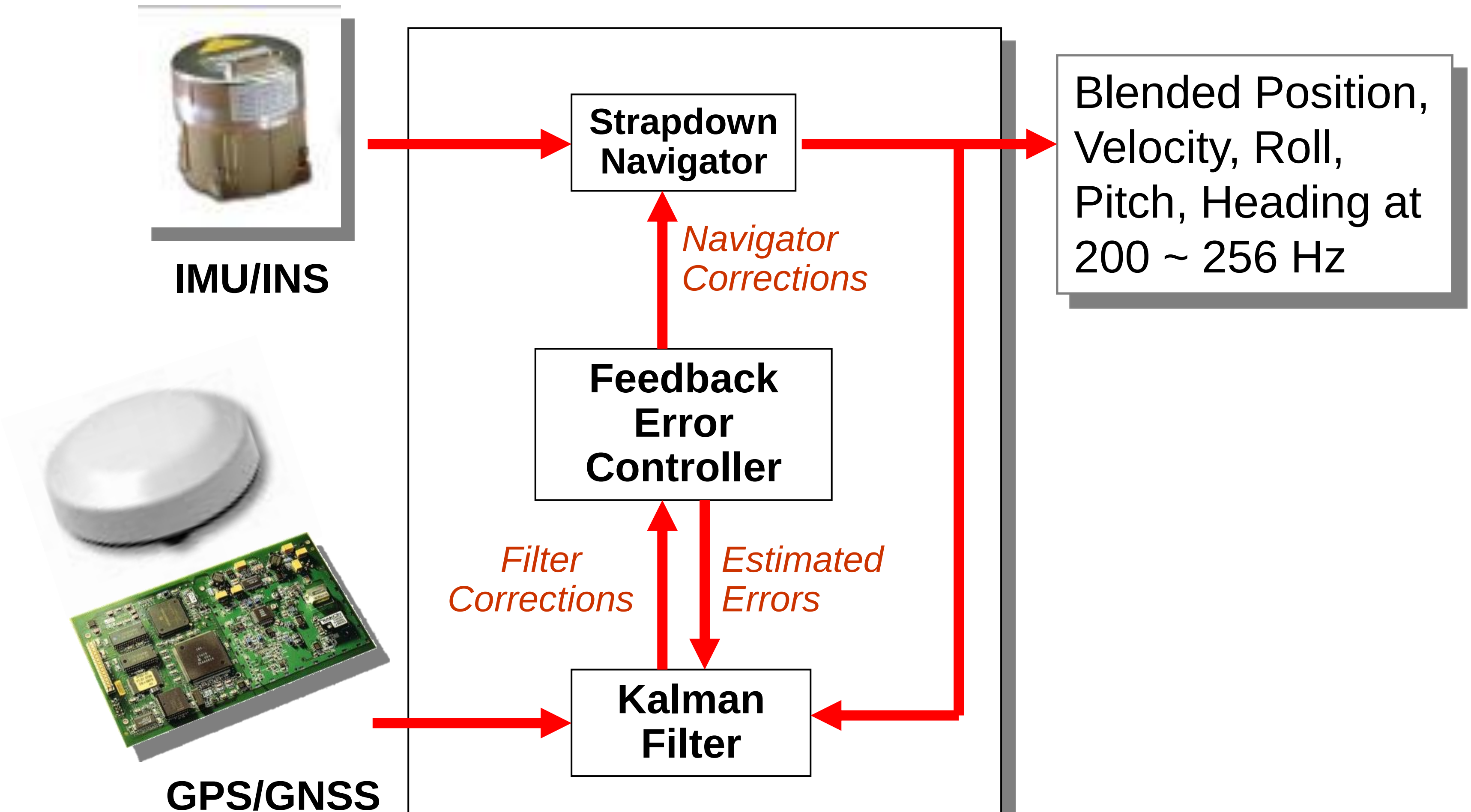


(Courtesy Applanix)

Changes in Surveying?

- **Measurements:**
  - From ground to space: distances, angles, signal intensity, time
  - From individual observation to multiple, simultaneous, shared, dynamic observations
- **Visibility Conditions:**
  - Ground observations: Visibility between instrument and target
  - Sensing from the space to the ground (photogrammetry, remote sensing) and receiving signals from the space（GPS）
- **Coordinate Computations:**
  - Coordinate Geometry (COGO)
- **Presentation:** Maps, 3D visualization (VR, AR), Web Browsing
  - What You See Is What You Get?

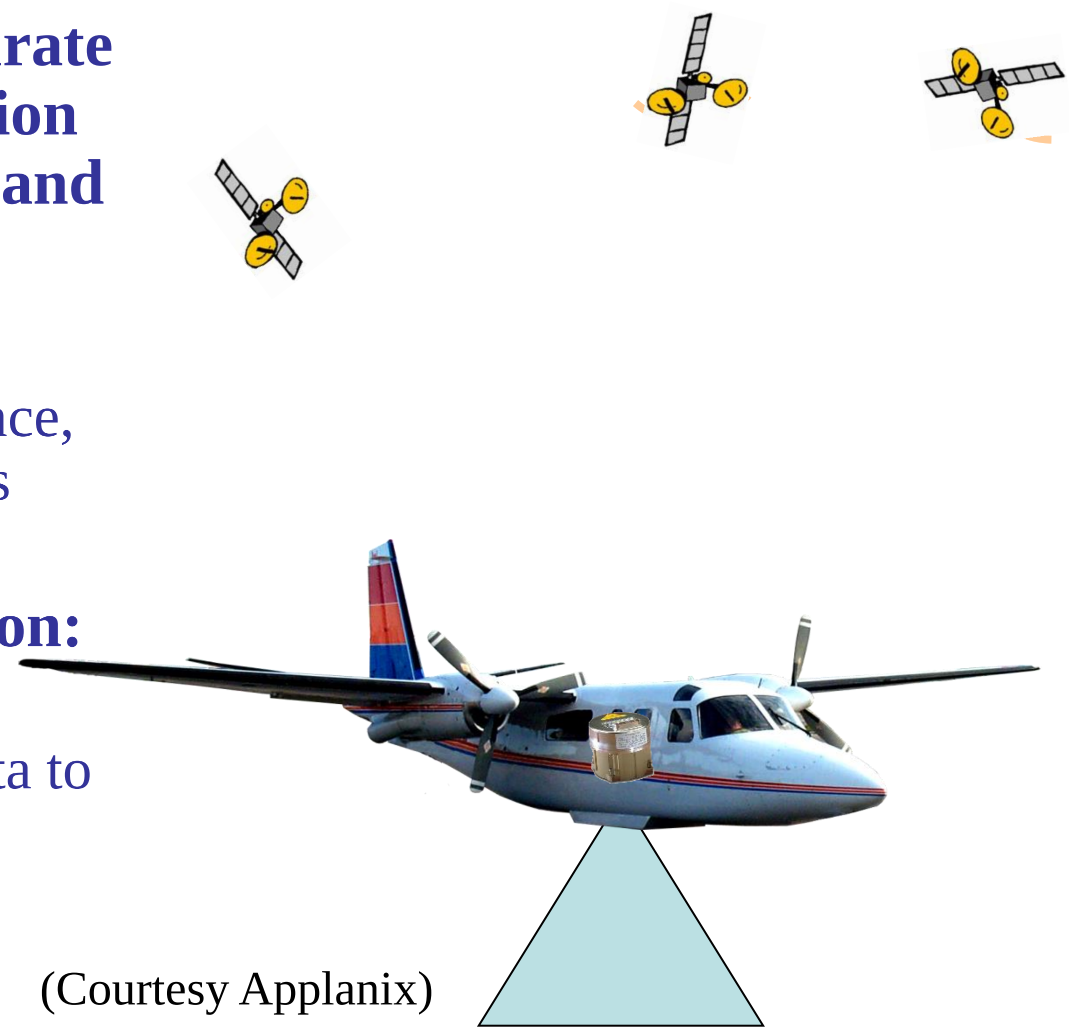
Position and Orientation System (POS)



(Courtesy Applanix)

GPS/GNSS-Aided Inertial Navigation

- **Produces highly accurate position and orientation from the GPS/GNSS and Inertial data**
- **Real-time solution:**
  - Used for pilot guidance, sensor control, 3-axis mount stabilization
- **Post-processed solution:**
  - Used to directly geo-referenced sensor data to high-accuracy



(Courtesy Applanix)

Concept of Direct Georeferencing

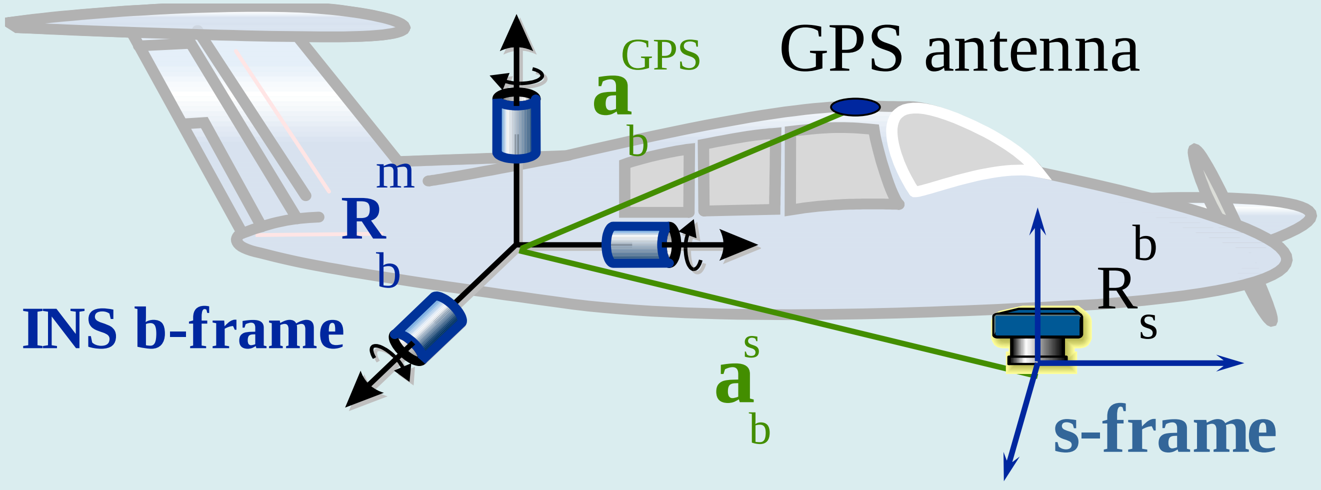
- The *collinearity concept* in photogrammetry is the basis for all direct georeferencing formula, where the image coordinates r_i^s of an object point *i* measured in the imaging sensor's coordinate frame are related to its object coordinates r_i^m in the mapping coordinate frame in a 3-D conformal transformation:

$$\mathrm{r}_i^m = \mathrm{r}_s^m + \mu_i \, \mathrm{R}_s^m \, \mathrm{r}_i^s$$

in which μ_i is the scale factor of the point *i*

R_s^m is the rotation matrix from the sensor's frame to the mapping frame upon the sensor's attitudes.

Transformation between Coordinate Frames



$$\mathrm{r}_i^m = \mathrm{r}_s^m + \mu_i \mathrm{R}_s^m \mathrm{r}_i^s$$

$$\mathrm{r}_s^m = \mathrm{r}_b^m + \mathrm{R}_s^m \mathrm{a}_b^s$$

$$\mathrm{R}_s^m = \mathrm{R}_b^m \mathrm{R}_s^b$$

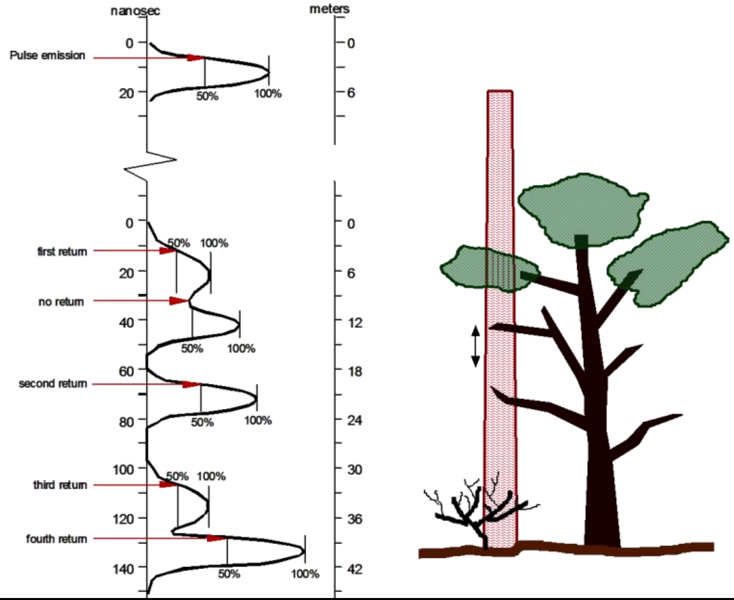
(Chiang，2009)

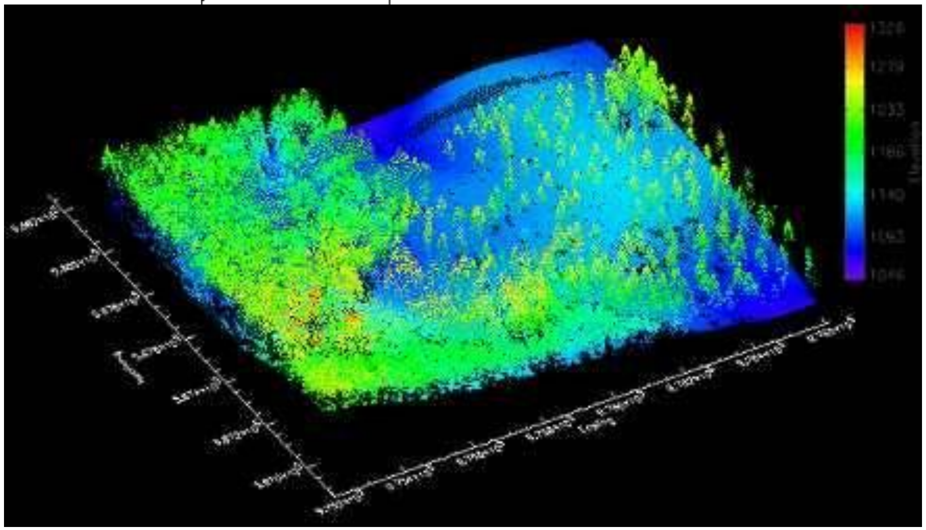
Procedures in Direct Georeferencing

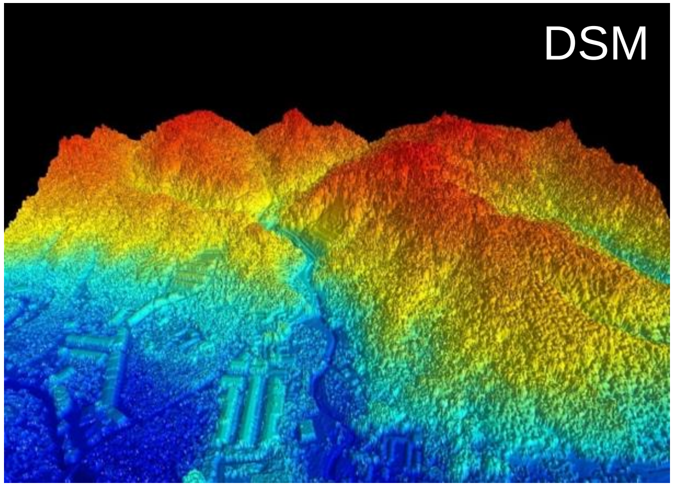
1. Measures translation and rotation of the Imaging Sensor and/or Laser Scanner using Navigation Sensors (GPS+INS or GPS+IMU), i.e., lever-arm offset and boresight calibration,
2. Measures range and bearing to points on the ground using the imaging sensor, e.g., digital camera, or laser scanner, e.g., LiDAR, i.e., sensor initialization,
3. Computes position of points on ground to corresponding points in the mapping frame without GCP using 3-D conformal transformation.

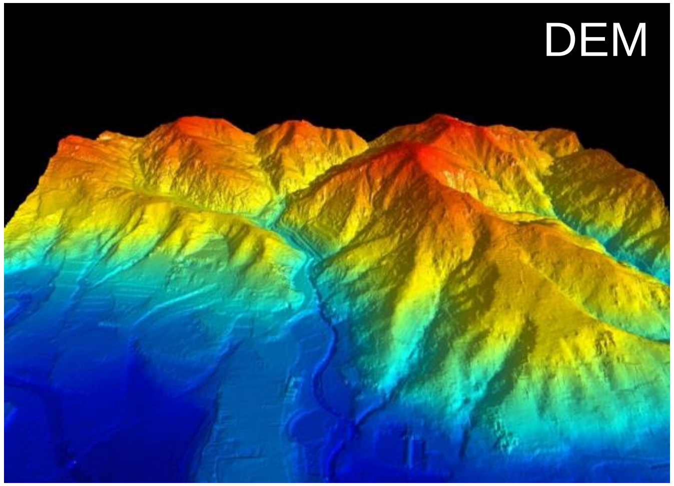
Can be applied with any type of sensors (active or passive).

III.1 DG-based Airborne LiDAR







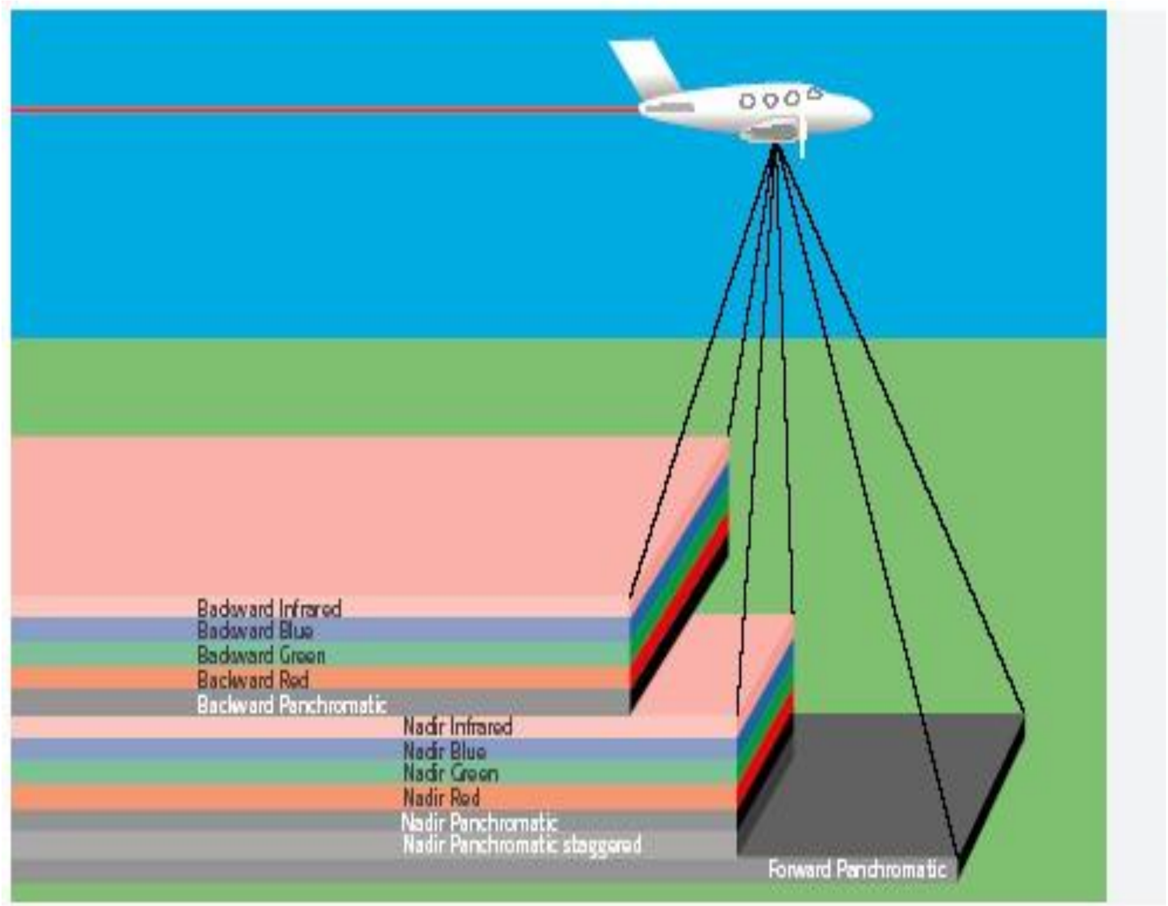


(After Tseng，2016)

III.2 DG-based Aerial Imaging Sensors

- Direct Georeferencing for Aerial Digital Cameras
- POS (GPS+IMU) provides direct measurements of camera exterior orientation parameters
    - Images can be automatically mosaicked together, and each pixel assigned a ground coordinate
    - No need for surveyed ground control points
- Increased productivity:
    - Generate ortho-rectified images and maps quickly and efficiently using few or no ground controls
    - Generate data for digital surface model (DSM) and digital elevation model (DEM)

III.2.1 Leica ADS40 Series



(Courtesy Leica Geosystems)

III.2.2 Z/I Imaging DMC Series

DMC (Digital Modular Camera)

DMC $II_{140,\ 230,\ 250}$

III.2.3 Vexcel UltraCam *Cameras*

UltraCam$_X$

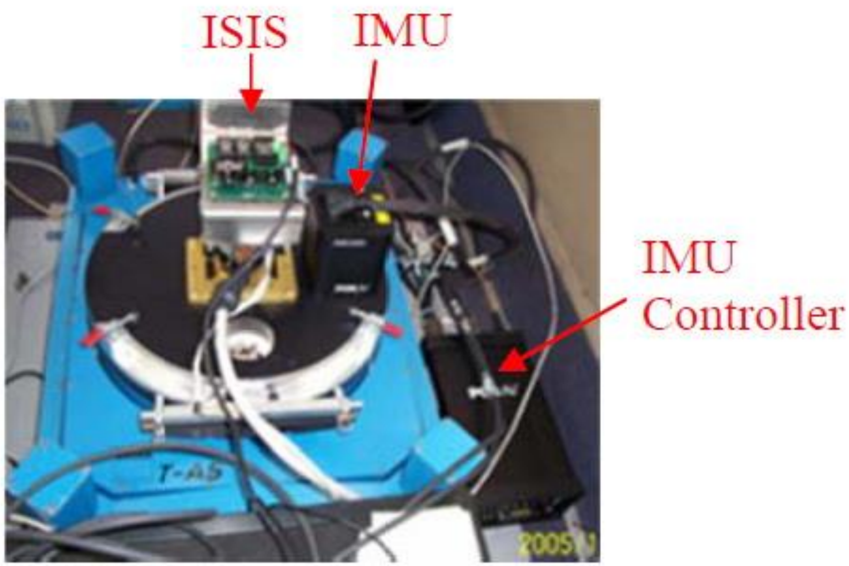
UltraCam$_D$

(Courtesy Vexcel)

III.2.4 ITRC Intelligent Spectral Imaging Scanner (ISIS)

- 218 spectral bands (bandwidth=2.4nm), each with 1150 pixels, share the same optical system with focal length 19mm, POS AV 510 included (Lee, 2007)

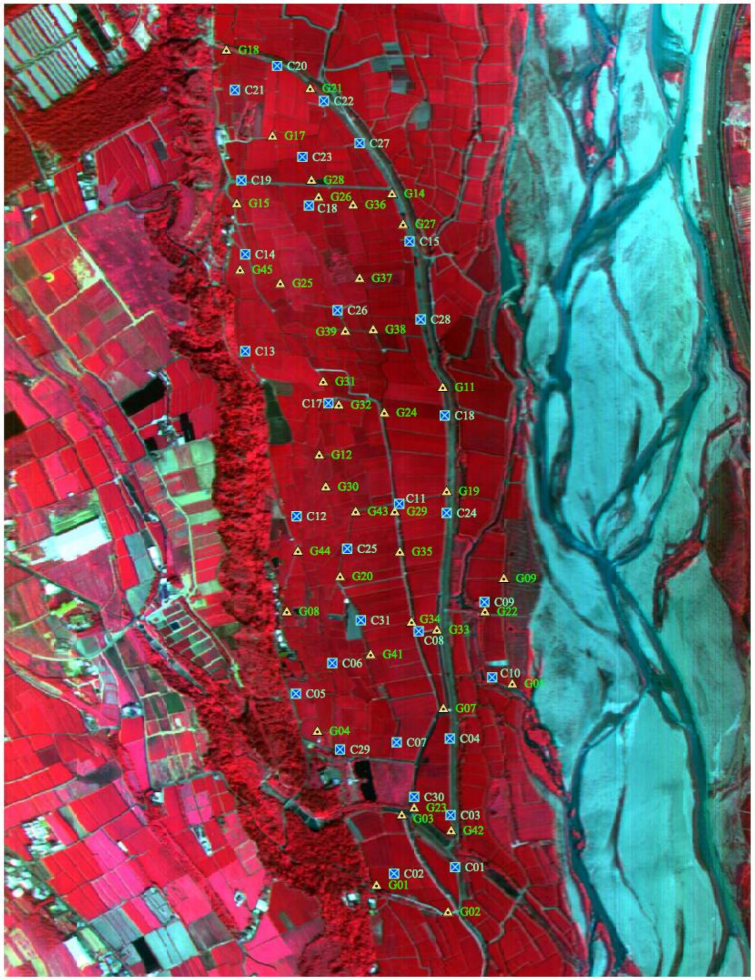
(a) BN-2A aircraft (Courtesy Great Wing Airline)



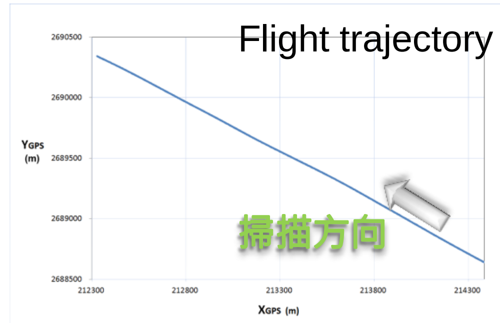
(b) ISIS and IMU on a T-AS platform

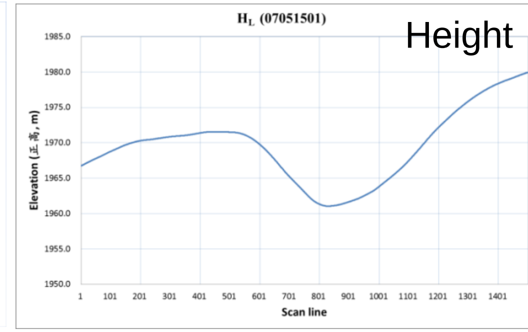
(Yeh & Tsai, 2011, 2015)

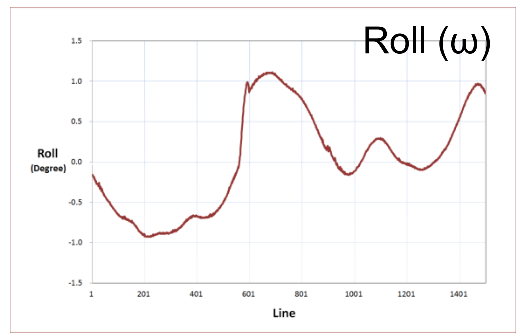
Raw ISIS Image with Flight Information

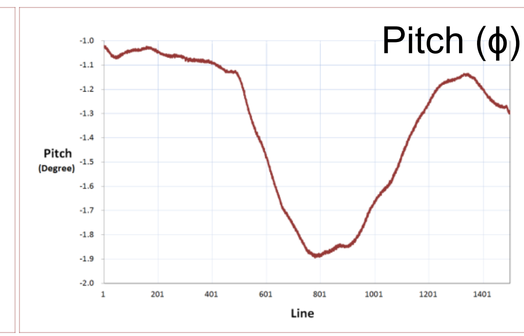


Original Raw Image (GSD=1.90m)





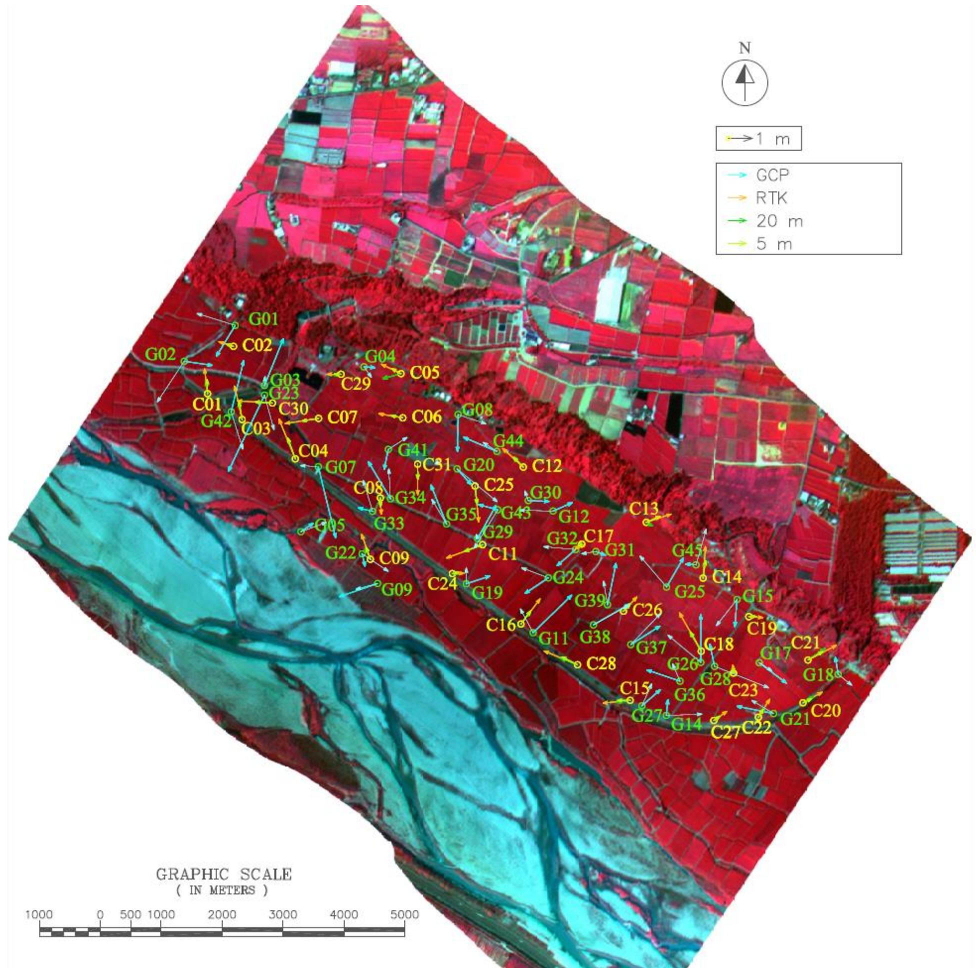




(Yeh，2014)

Self-Calibrated DG-19 Rectified ISIS Image

Parameter	Calibrated value
X_{la}	-0.0024 m
Y_{la}	-0.1307 m
Z_{la}	0.0497 m
ω_o	0.0094 rad
ϕ_o	0.0120 rad
κ_o	0.0153 rad
S_ω	1.0065
S_ϕ	1.0000
S_κ	0.9992
δc	1.0000
f	0.0190 m
x_0	$1.523\text{x}10^{-8}$ m
y_0	$-0.723\text{x}10^{-8}$ m
K_0	$2.7980\text{x}10^{-5}$
K_1	$-1.0195\text{x}10^{-5}$
K_2	$9.9417\text{x}10^{-7}$
K_3	$-2.8630\text{x}10^{-8}$
P_1	$2.9334\text{x}10^{-13}$
P_2	$-8.3500\text{x}10^{-13}$



$\sigma_0 = 2.413m\ (1.27pixels)$

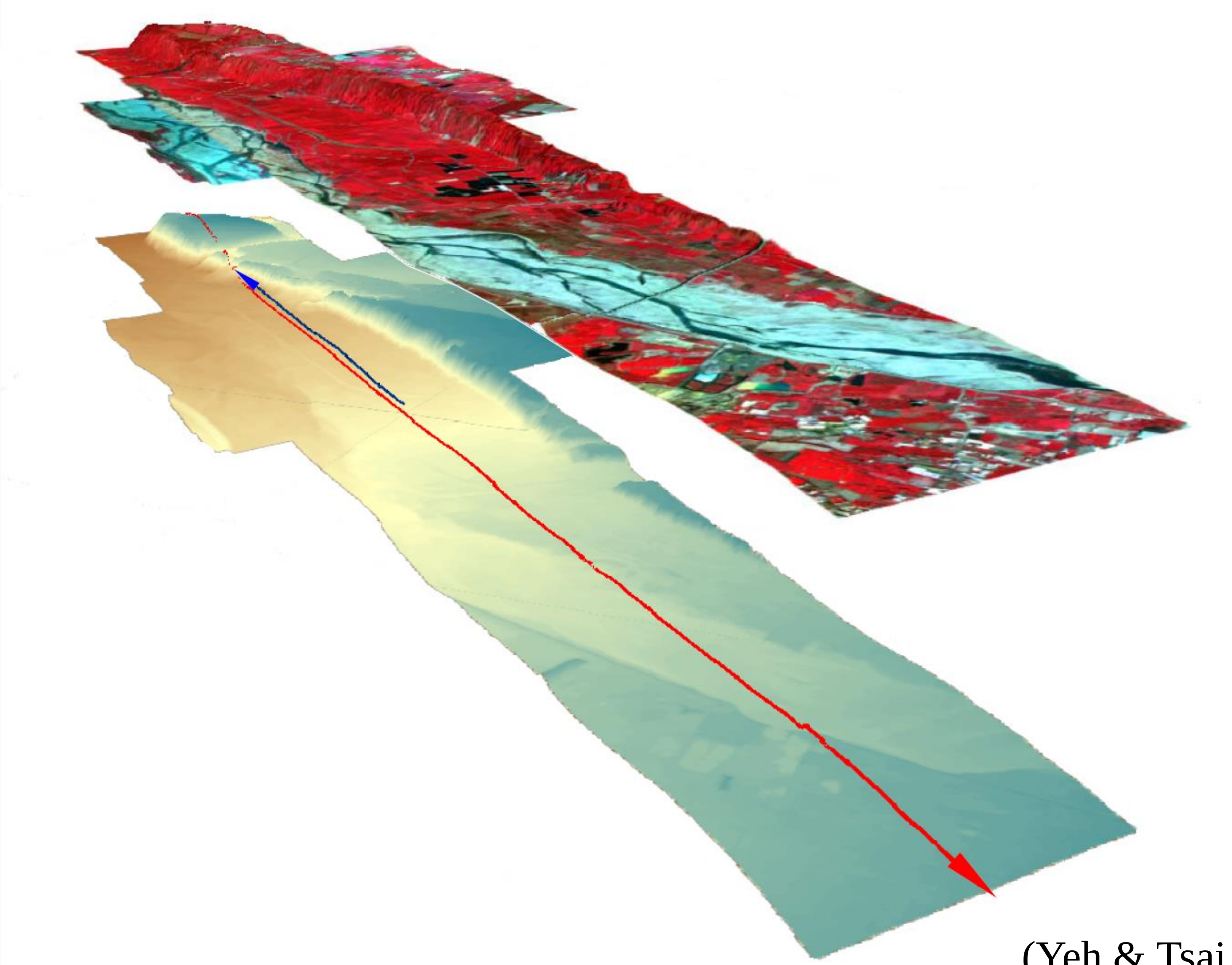
(Yeh & Tsai, 2015)

Quality in DG-Rectified ISIS Image

Points	Method	$RMSE_X$	$RMSE_Y$	$RMSE_{X-Y}$	$RMSE_H$
Ground control points (40 G's)	In-flight DG	8.791 m	26.827 m	28.231 m	2.148 m
	Self-calibrated DG-19	1.742 m	2.379 m	2.949 m	2.450 m
Ground check points (30 C's)	20-m DEM DG-19	1.727 m	1.712 m	2.431 m	4.806 m
	5-m DEM DG-19	1.653 m	1.729 m	2.392 m	2.420 m
	GPS-RTK DG-19	1.656 m	1.662 m	2.347 m	2.218 m

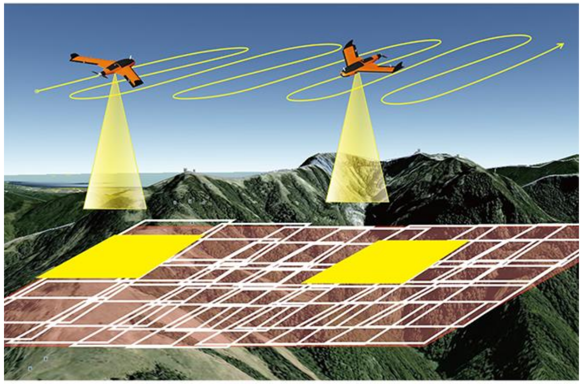
(Yeh & Tsai, 2015)

3-D View of Two DG-19 Rectified Images on 5-m DEM



(Yeh & Tsai, 2015)

III.3 UAV/UAS/UAVS Applications



(After Tseng, 2016)

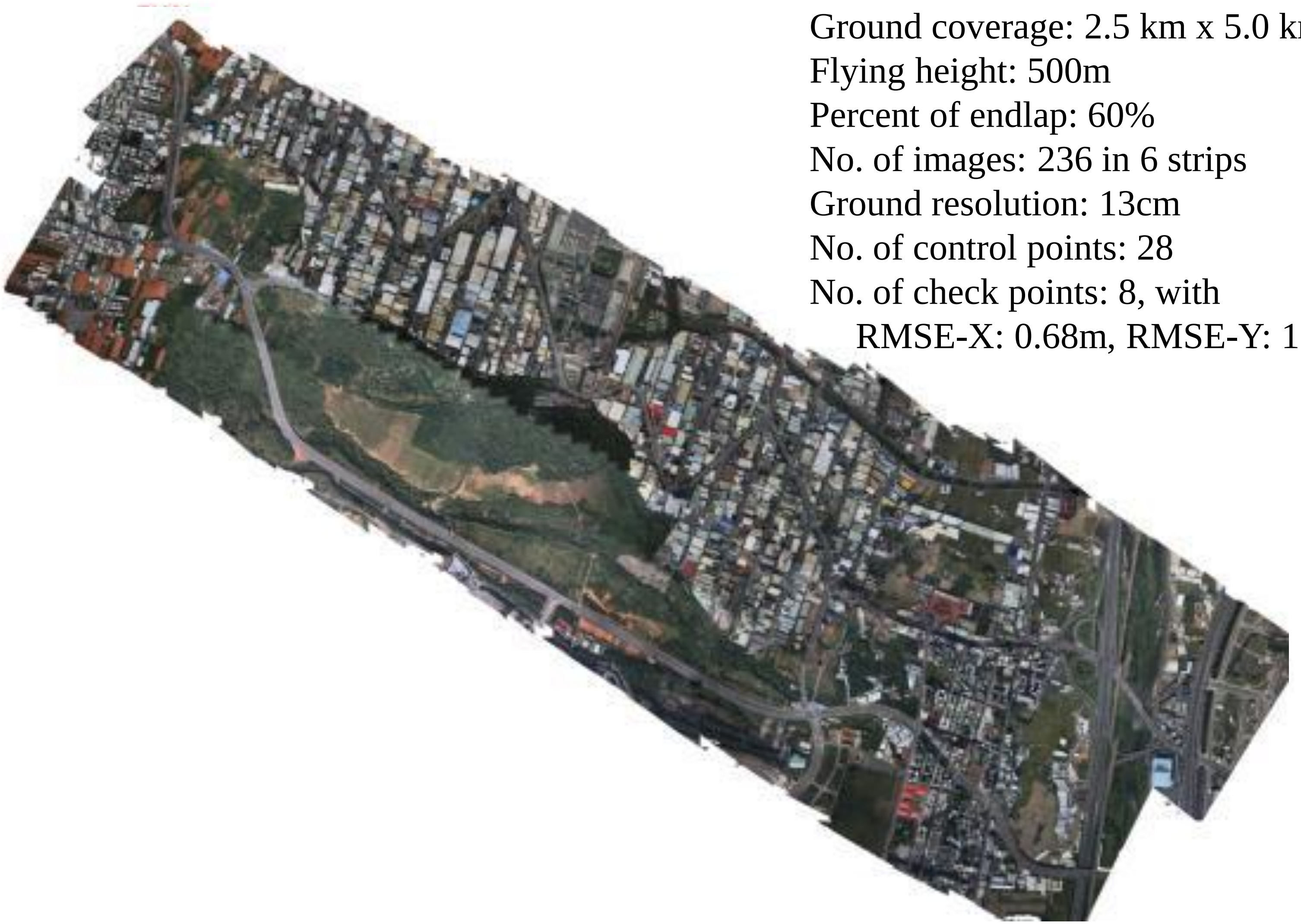
III.3.1 National Land Surveying and Mapping Center (NLSC), Ministry of the Interior, Taiwan

- NLSC proceeded two 4-year projects on *Development of UAS Aerial Mapping Technology*:
  - First phase (2011-2014): Investigation of platform and sensor integration, algorithm and program development, test flights for producing orthoimage mosaics
  - Second phase (2015-2018): on-going projects by year for implementation of multi-camera and multi-sensor on a multi-drone UAS for 3-D *point cloud* and 3-D city model reconstruction

NLSC-1 UAS (NLSC, 2015)

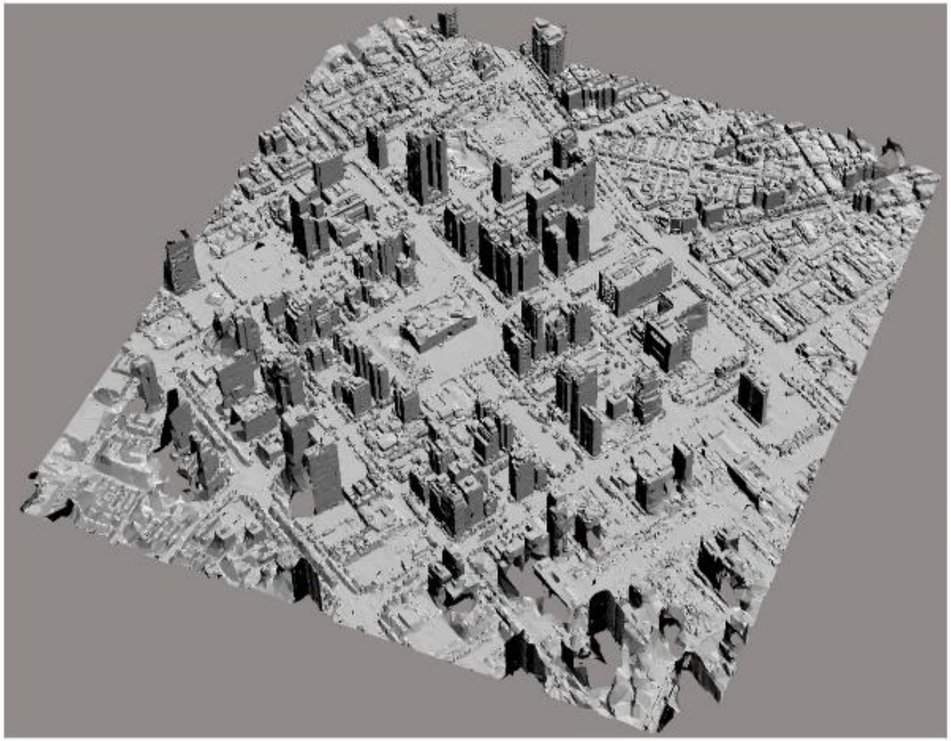
Multi-camera UAS (NLSC, 2016)

25-cm Orthoimage Mosaics of Taichung Industrial Park, Taiwan (NLSC, 2011)

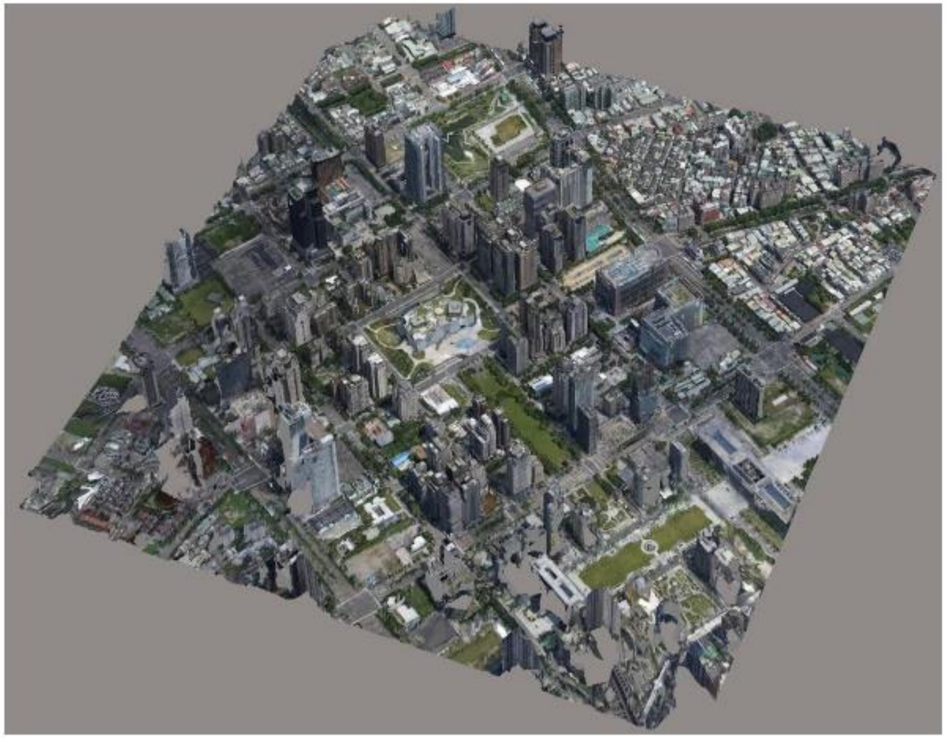


Ground coverage: 2.5 km x 5.0 km
Flying height: 500m
Percent of endlap: 60%
No. of images: 236 in 6 strips
Ground resolution: 13cm
No. of control points: 28
No. of check points: 8, with
RMSE-X: 0.68m, RMSE-Y: 1.73m

Point Cloud & 3-D Models Reconstructed from UAS Multi-Camera Images around National Taichung Theater, Taiwan (NLSC, 2016)

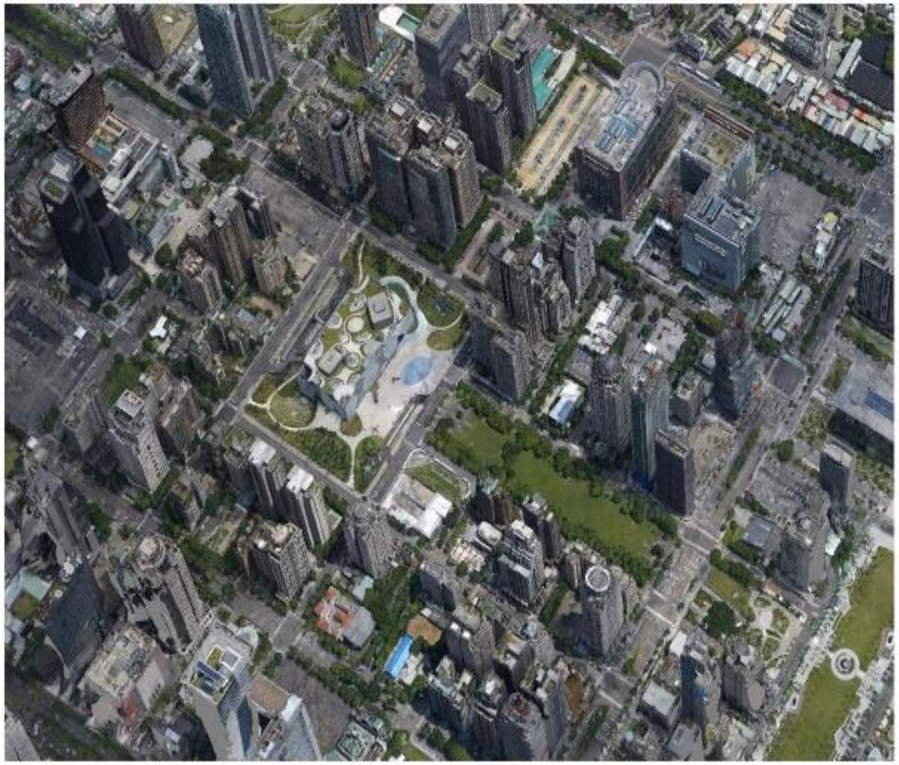


3-D *point cloud*



3-D image model

Point Cloud & 3-D Models Reconstructed from UAS Multi-Camera Images around National Taichung Theater, Taiwan (NLSC, 2016)



3-D model from 3-camera images (Sony QX-1)

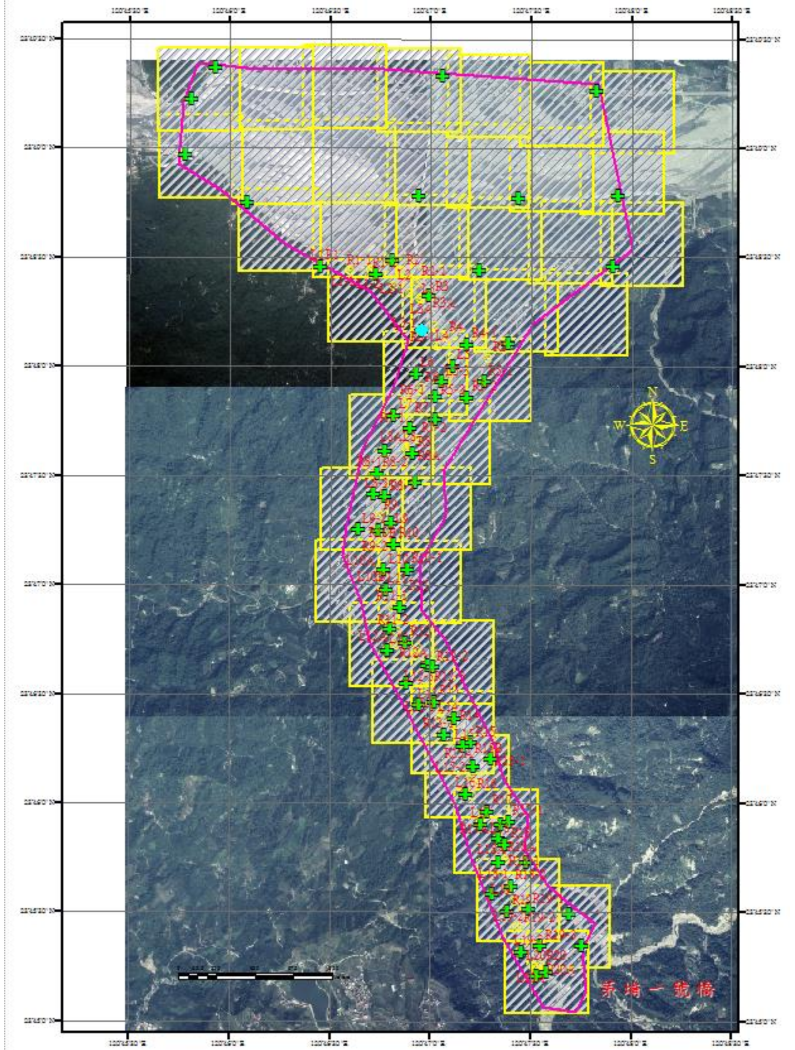
3-D model from 5-camera images (Sony QX-10)

3-D Model Reconstructed from UAS & MMS Images around National Taichung Theater, Taiwan (NLSC, 2016)

III.3.2 Water Resource Agency (WRA), Ministry of Economic Affairs, Taiwan

- Stream course topographic mapping and orthoimage production (The 3rd River Management Office)
- UAS + Non-metric Camera
  - Upstream: Avian-p+Sony A5100
  - Junction: Mikrokopter+Sony A5600
- Control Surveying:

  GPS-RTK



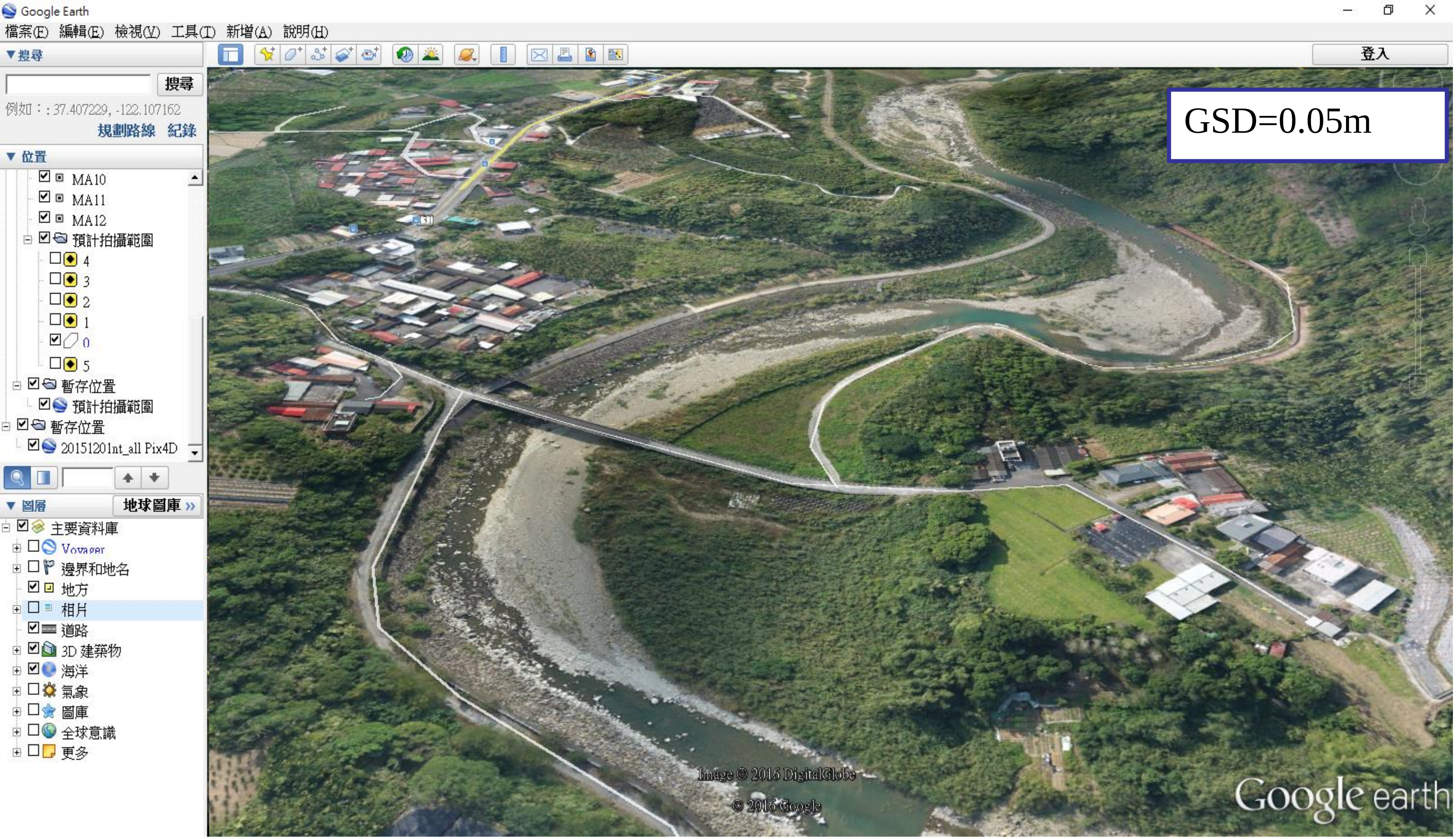
(Yeh, 2016)

UAV Orthoimage Production along A Stream Course

Area : 10.03 KM^2
Num. of Images : 1480/1507
GSD : 8.16cm
Num. of GCPs : 47 (3D)

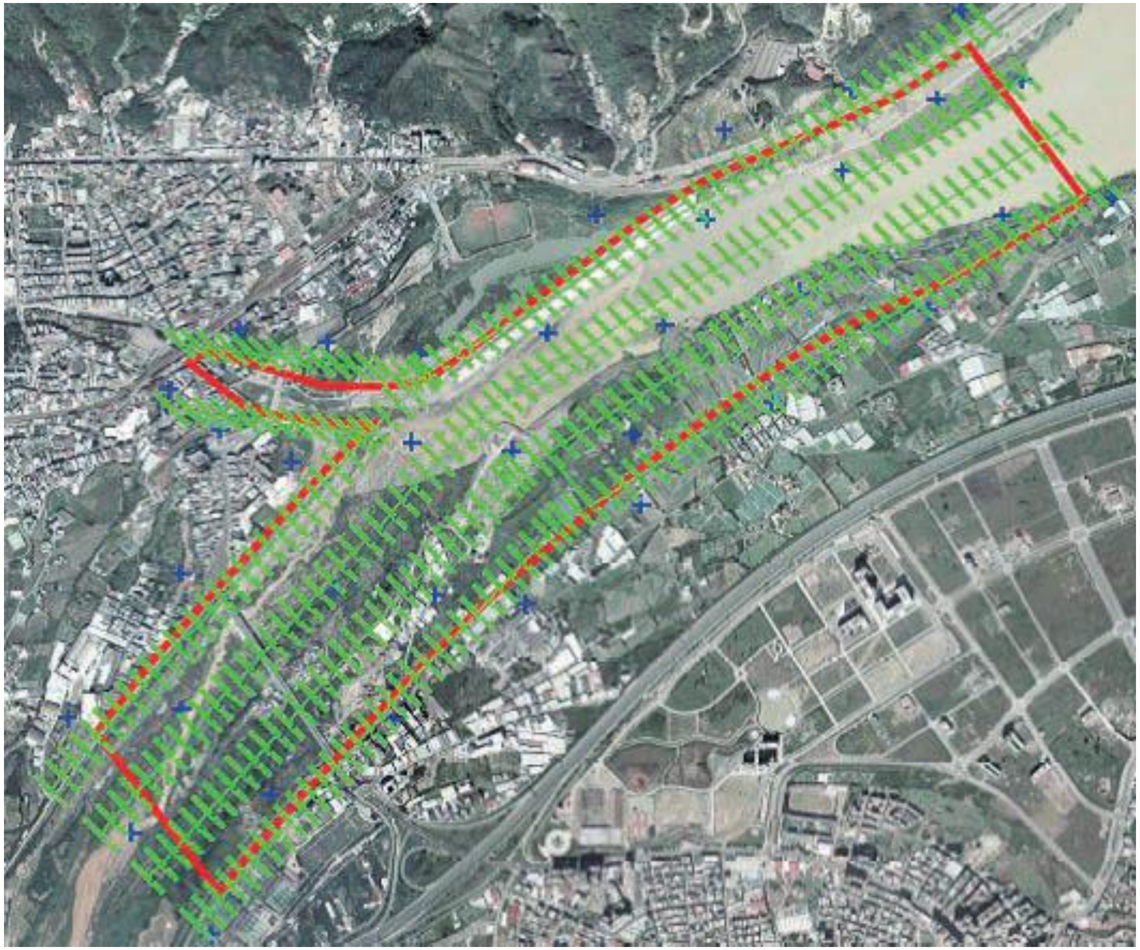
Images	median of 84619 keypoints per image
Dataset	1480 out of 1507 images calibrated (98%), all images enabled, 4 blocks
Camera Optimization	1.12% relative difference between initial and optimized internal camera parameters
Matching	median of 13998.7 matches per calibrated image
Georeferencing	yes, 47 GCPs (47 3D), mean RMS error = 0.019 m

Orthoimage Overlay on Google Earth



III.3.3 CECI Engineering Consultants, Inc. (Lin *et al*, 2015)

- **AI-RIDER YJ-1000-HC UAV + Canon EOS 5D Mark II**



- 622 images in 10 strips with 6.8cm ground res.
- self-calibrated bundle adjustment RMSE: 0.04m in plane and 0.10m in elevation of 30767 points
- standard errors of map are 0.198m in plane and 0.0034m in elevation

IV. Conclusions

- This paper presents a review and examination on Surveying technologies based on light geometry, including *radiation*, *radial traversing*, *intersection*, *resection*, photogrammetric *aerotriangulation*, and the latest *direct georeferencing* (DG) techniques.
- Although new high-tech instruments based on various methods have revolutionized field activities and practices of the surveyor's profession in Surveying, however, the fundamental concept and theory in light geometry remain unchanged.