Multi-Sensor Triangulation of Multi-Source Spatial Data

Ayman Habib, Chang-Jae Kim, and Ki-In Bang
Digital Photogrammetry Research Group

http://dprg.geomatics.ucalgary.ca

Department of Geomatics Engineering
University of Calgary, Canada

Overview

- Introduction.
- Multi-sensor triangulation.
- Multi-primitive triangulation:
  - Points.
  - Linear features.
  - Aerial features.
- Experimental results.
- Conclusions and future outlook.

Introduction

- There is a tremendous increase in data acquisition systems, which are available for the mapping community:
  - Photogrammetric systems:
    - High resolution imaging satellites.
    - Metric analog frame cameras.
    - Metric digital frame cameras.
    - Metric digital line cameras.
    - Medium-format digital frame cameras.
  - LIDAR systems.
  - GPS/INS navigation units.
- These systems provide complementary information.
- We need to provide an integrating environment of these sensors: Multi-Sensor Triangulation (MST).

Photogrammetric Systems

Frame Cameras

RC10

DMC

Applanix DSS

Kodak 14n

Canon EOS 1D

SONY 717

Line Cameras

ADS 40

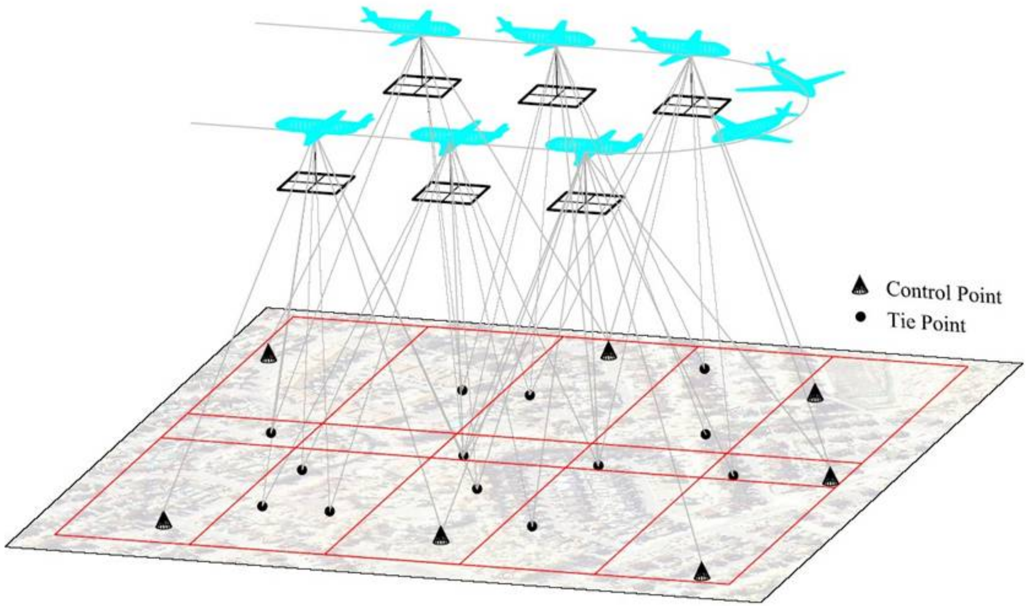
IKONOS

LIDAR Systems

ALS 40 (Leica Geosystems)

OPTECH ALTM 3100

Point-Based Triangulation



$$\begin{bmatrix} x_a - x_p - \Delta x \\ y_a - y_p - \Delta y \\ -c \end{bmatrix} = \lambda R^T \begin{bmatrix} X_A - X_0 \\ Y_A - Y_0 \\ Z_A - Z_0 \end{bmatrix}$$

Line-Based Triangulation

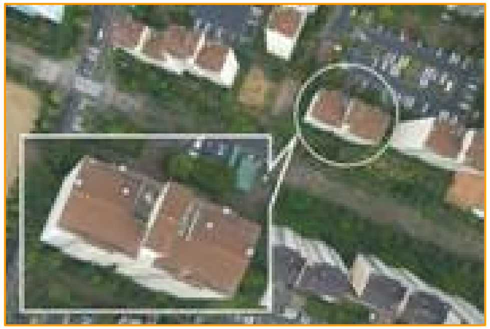
Photogrammetry:

Direct measurement of intermediate points on images

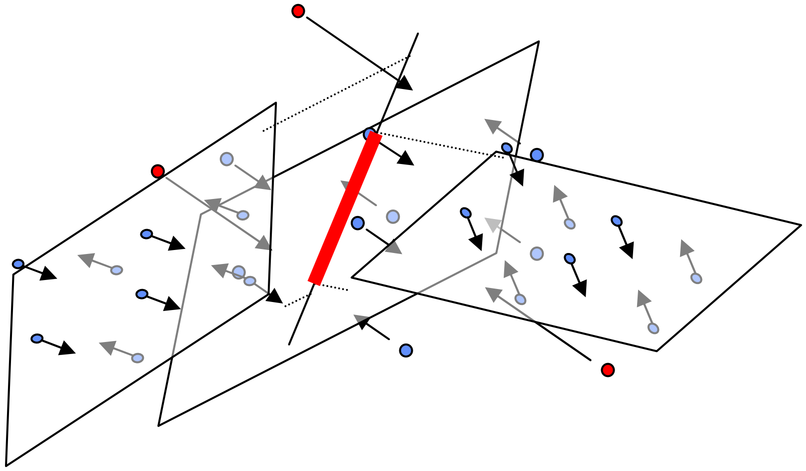
Line-Based Triangulation

LIDAR:

Plane fitting & intersection



manual identification of LIDAR
patches with the aid of imagery



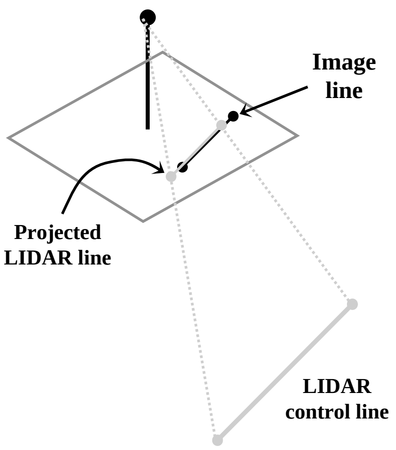
Line-Based Triangulation

LIDAR:

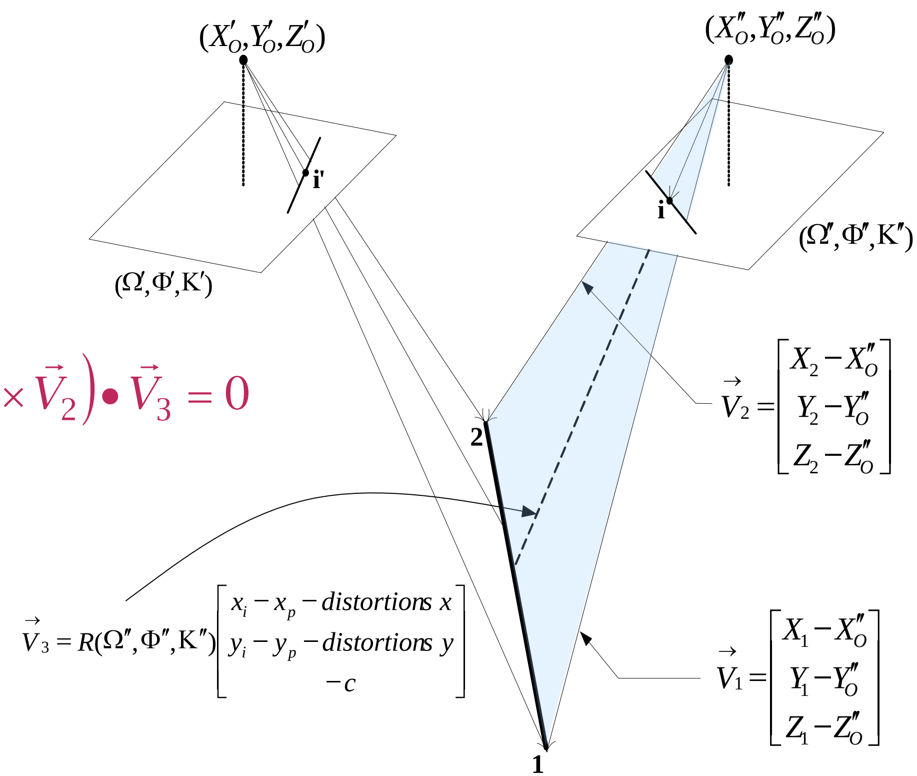
Manipulation of range and intensity images

Line-Based Triangulation

Direct incorporation of LIDAR lines as control in the photogrammetric BA

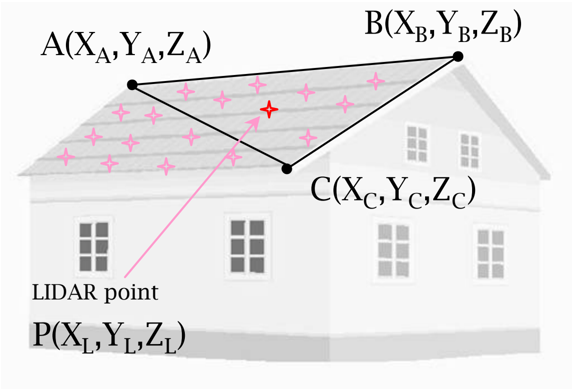


$$\left(\vec{V}_1 \times \vec{V}_2\right) \bullet \vec{V}_3 = 0$$



Patch-Based Triangulation

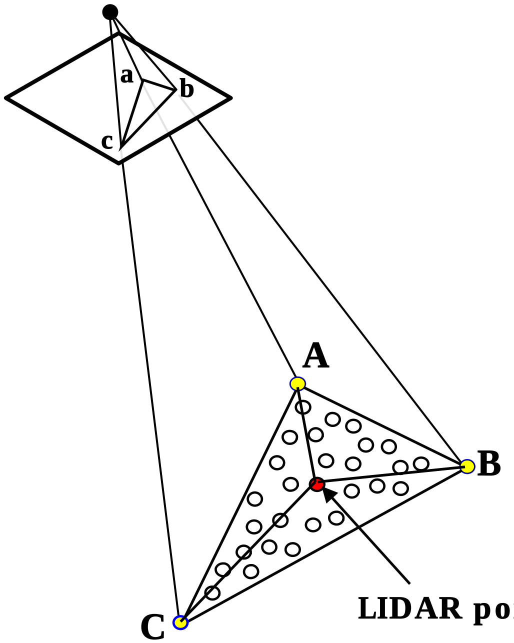
Direct incorporation of LIDAR patches as constraints in the photogrammetric BA



Photogrammetric (A,B,C points) and LIDAR surface patches

Patch-Based Triangulation

Direct incorporation of LIDAR patches as constraints in the photogrammetric BA



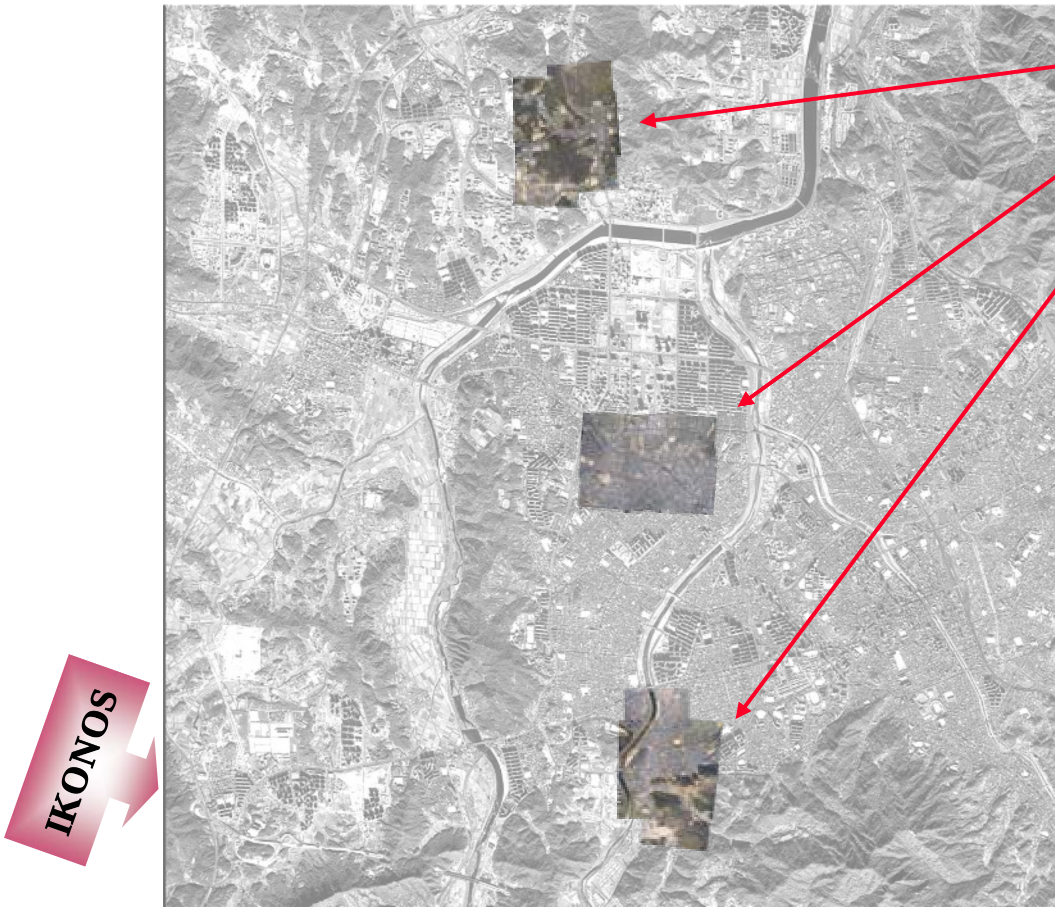
Volume of the pyramid:
i, A, B, C should = 0

$$\begin{vmatrix} X_i & Y_i & Z_i & 1 \\ X_A & Y_A & Z_A & 1 \\ X_B & Y_B & Z_B & 1 \\ X_C & Y_C & Z_C & 1 \end{vmatrix} = \begin{vmatrix} X_i - X_A & Y_i - Y_A & Z_i - Z_A \\ X_B - X_A & Y_B - Y_A & Z_B - Z_A \\ X_C - X_A & Y_C - Y_A & Z_C - Z_A \end{vmatrix} = 0$$

Multi-Sensor Triangulation (MST)

- Developed an integrated triangulation system.
  - Multi-sensor: Satellite imagery, aerial imagery, LIDAR and GPS/INS.
  - Multi-primitive: distinct points, linear features, and aerial features.
- Advantages:
  - Takes an advantage of the extended coverage of imaging satellites.
  - Takes an advantage of the high geometric resolution of aerial imaging systems.
  - Utilizes sparse frame imagery to improve the weak geometry of imaging satellites while reducing ground control point requirements.
  - Uses LIDAR data for photogrammetric geo-referencing.

MST: Experimental Results



DSS:

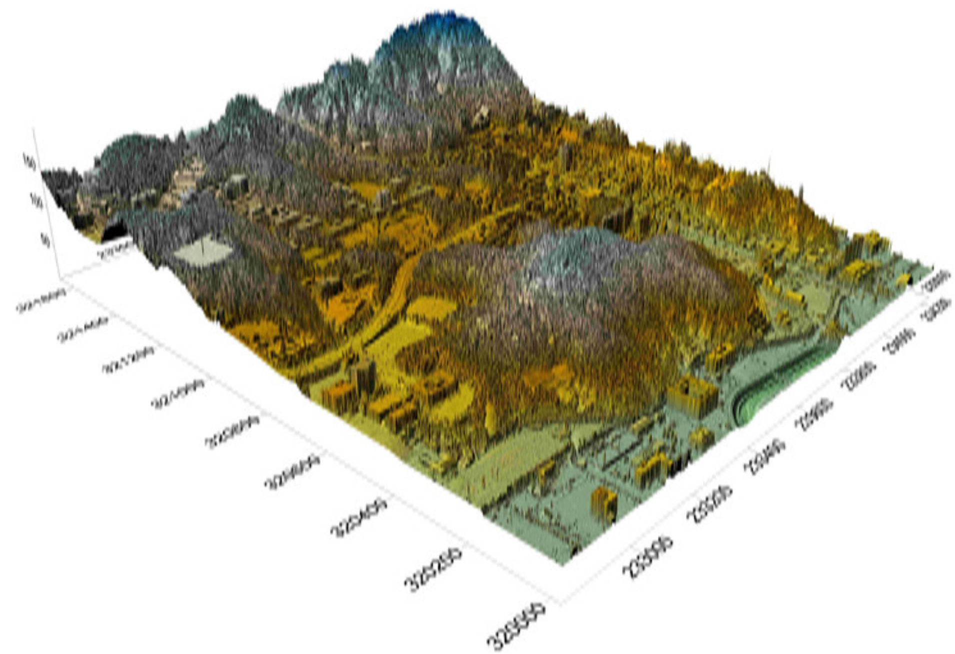
Expected accuracy:

planimetric: 0.25m
vertical: 0.74m
spatial: 0.78m

MST: Experimental Results

Upper Block

DSS: Upper Block

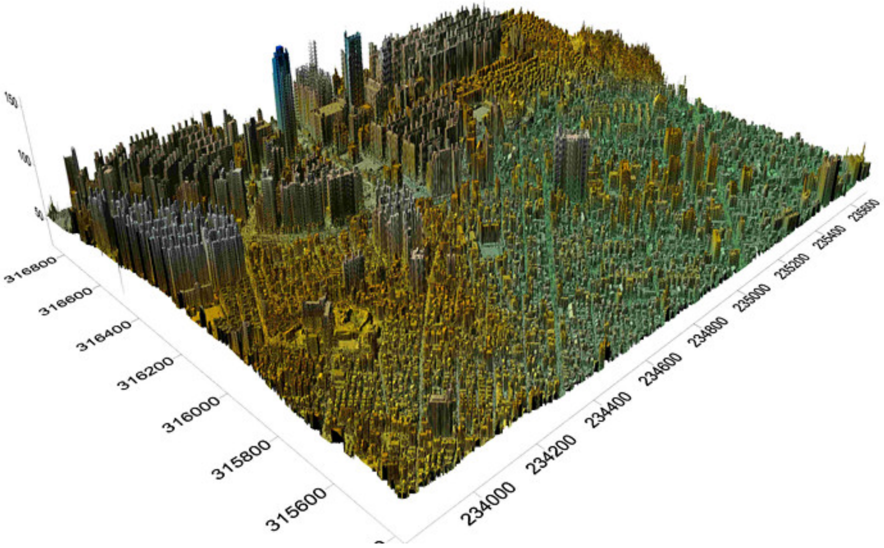


Upper LIDAR Scan

MST: Experimental Results

Middle Block

DSS: Middle Block

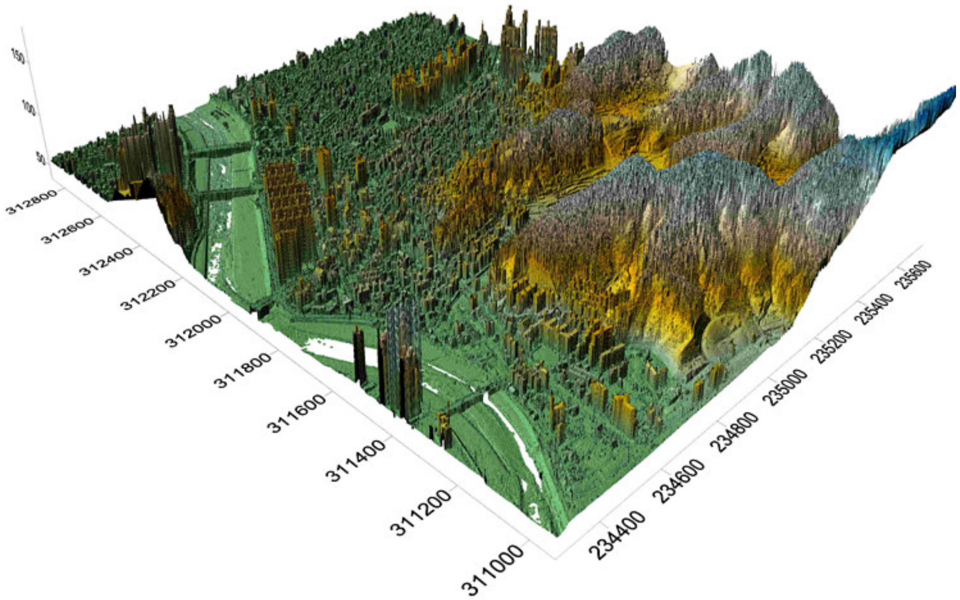


Middle LIDAR Scan

MST: Experimental Results

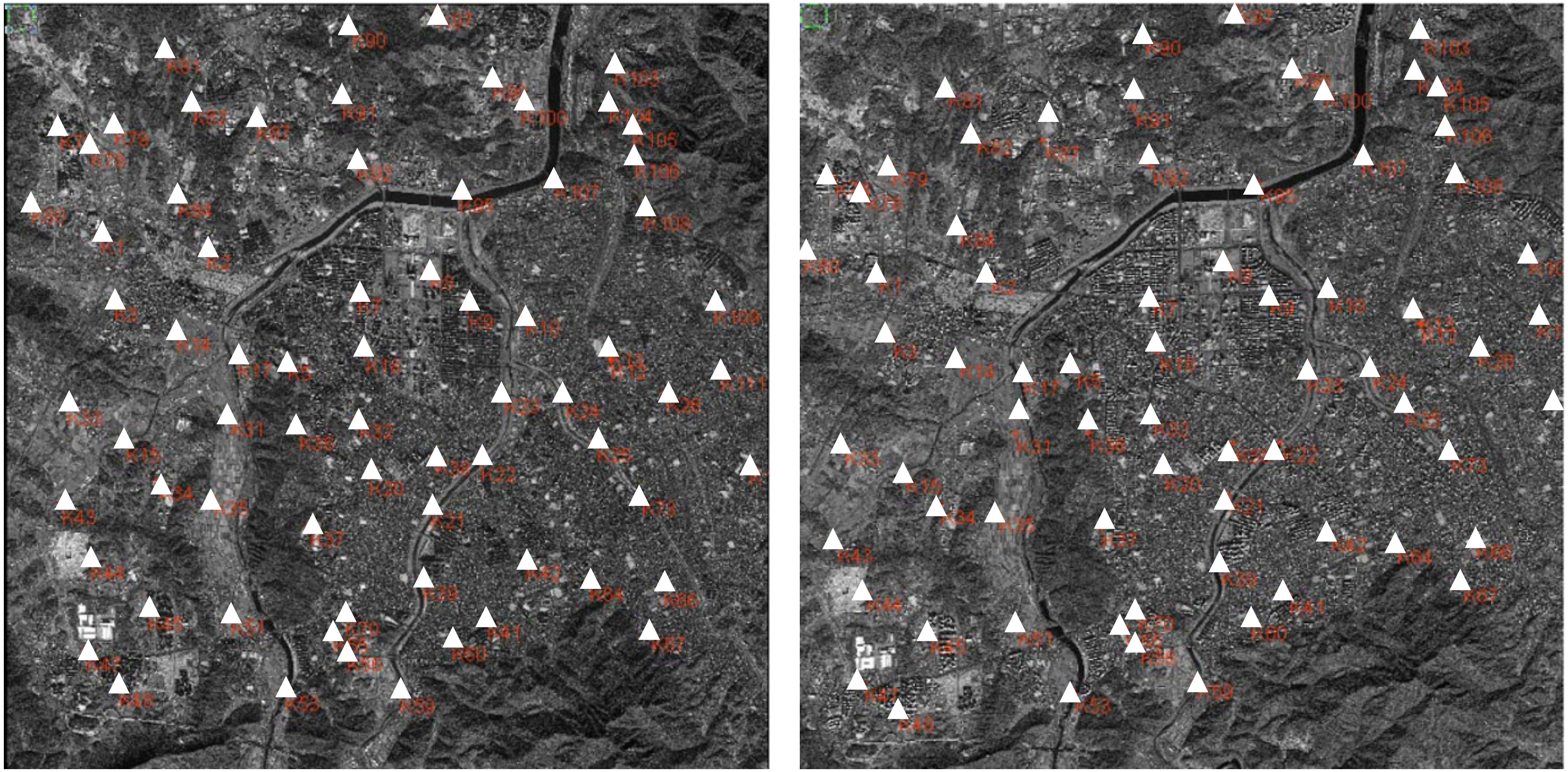
Lower Block

DSS: Lower Block



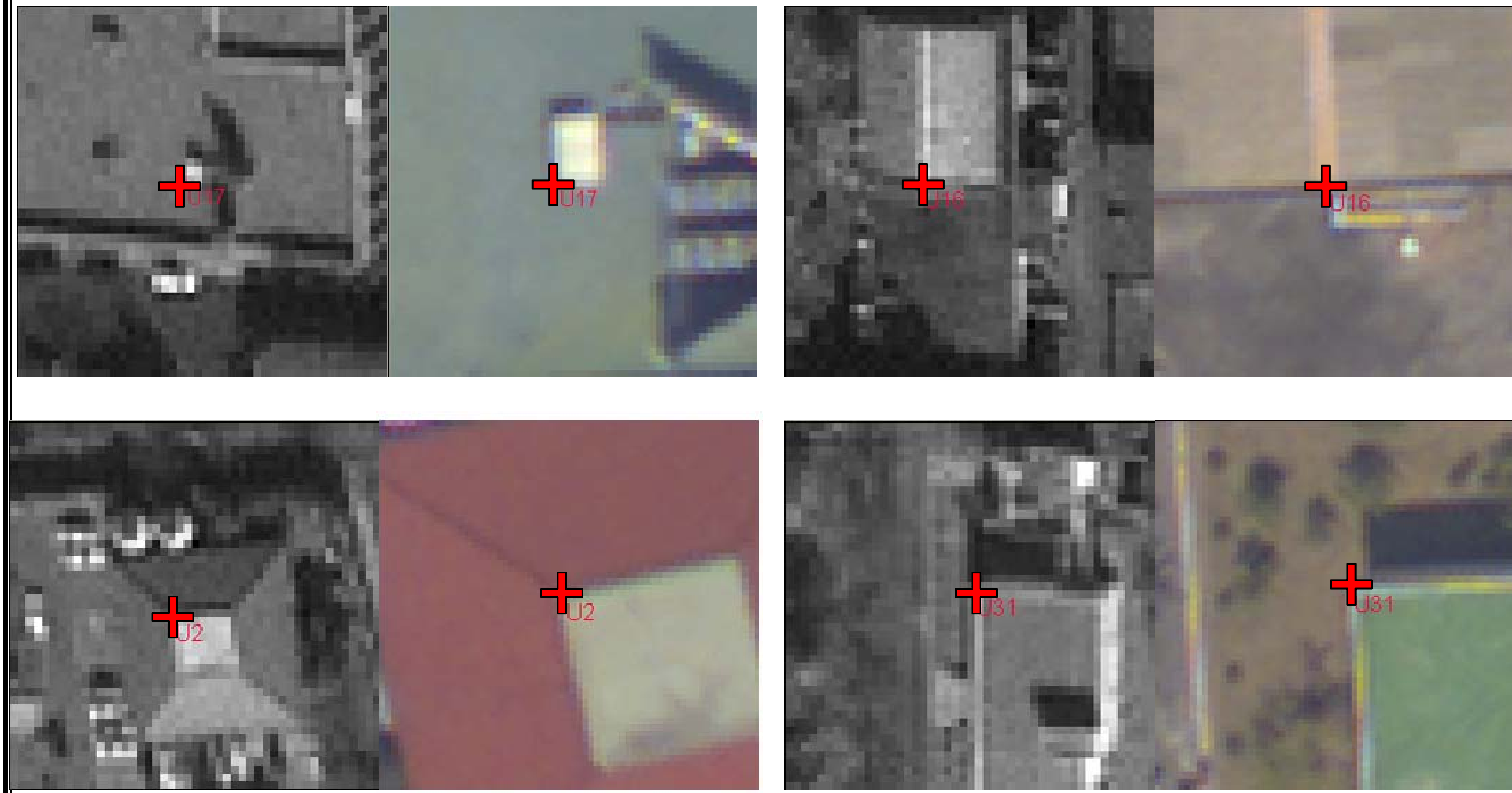
Lower LIDAR Scan

Stereo-IKONOS with GCP Layout



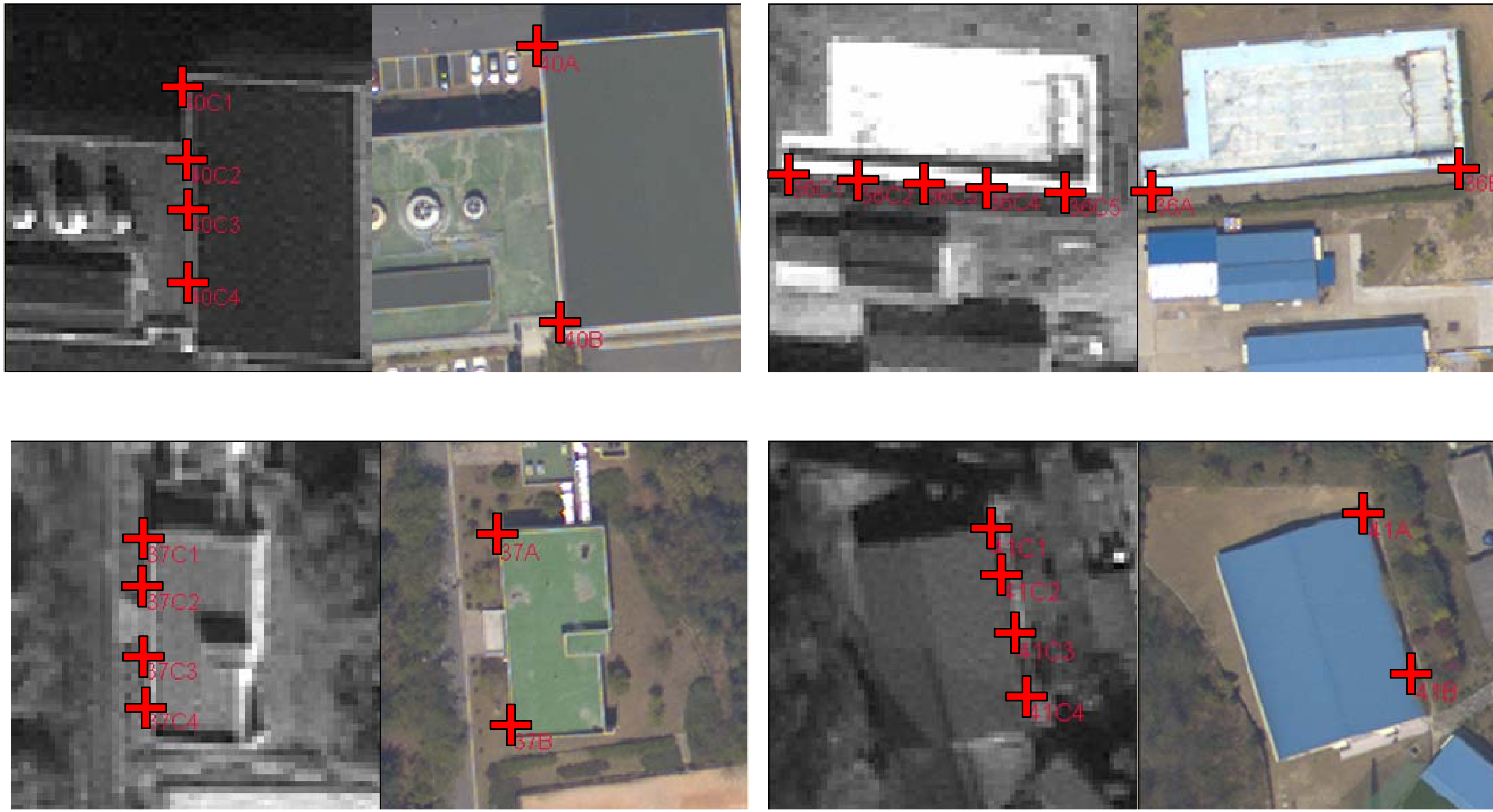
IKONOS scenes and GCP layout over Daejeon, Korea

MST: Experimental Results



Examples of Tie Points

MST: Experimental Results



Examples of Tie / Control Lines

MST: Experimental Results

Example of a Control Patch

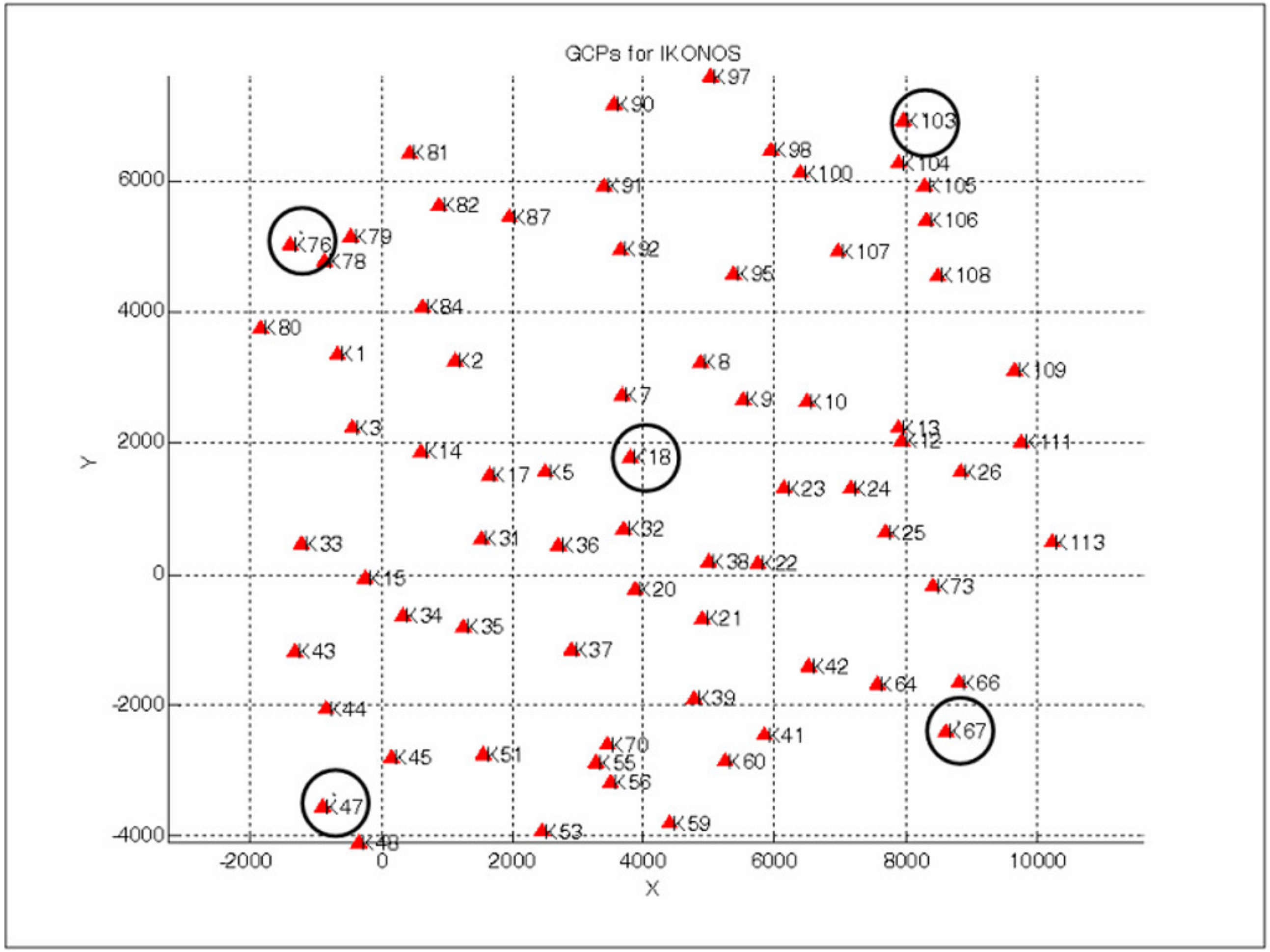
No Ground Control Points

# GCP	# Frames	GPS / LIN / PATCH	$\hat{\sigma}_0$ (mm)	RMSE (m)			
				X	Y	Z	Total
0	0	NONE	N/A	N/A	N/A	N/A	N/A
	18	NONE	N/A	N/A	N/A	N/A	N/A
		LIN	0.005	2.105	1.370	1.757	3.065
		PATCH	0.004	3.582	3.394	2.207	5.406
		GPS	0.006	2.109	1.048	1.963	3.066
		GPS + LIN	0.005	2.116	1.358	1.803	3.093
		GPS + PATCH	0.004	2.374	2.580	2.294	4.190

138 Control Lines & 139 Control Patches

Scan line direction

Configuration of 5 GCP



Scan line direction

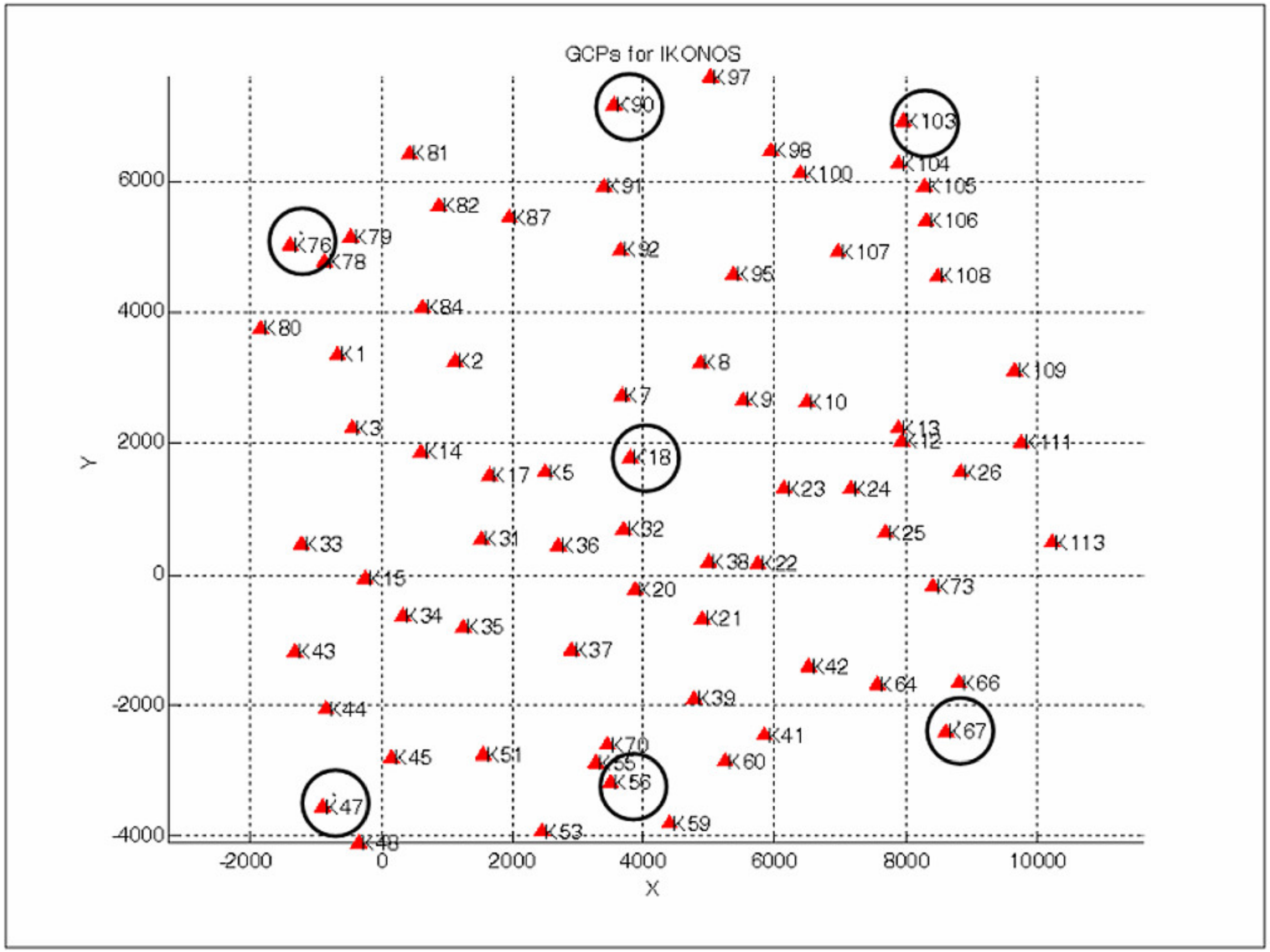
5 Ground Control Points

# GCP	# Frames	GPS / LIN / PATCH	$\hat{\sigma}_0$ (mm)	RMSE (m)			
				X	**Y**	**Z**	**Total**
5	0	NONE	N/A	N/A	N/A	N/A	N/A
	18	NONE	0.006	1.907	1.084	3.7474	4.342
		LIN	0.005	1.786	1.115	1.717	2.716
		PATCH	0.004	1.670	1.009	1.759	2.628
		GPS	0.007	1.805	1.024	1.770	2.727
		GPS + LIN	0.005	1.733	1.112	1.717	2.681
		GPS + PATCH	0.004	1.647	1.008	1.786	2.631

138 Control Lines & 139 Control Patches

Scan line direction

Configuration of 7 GCP



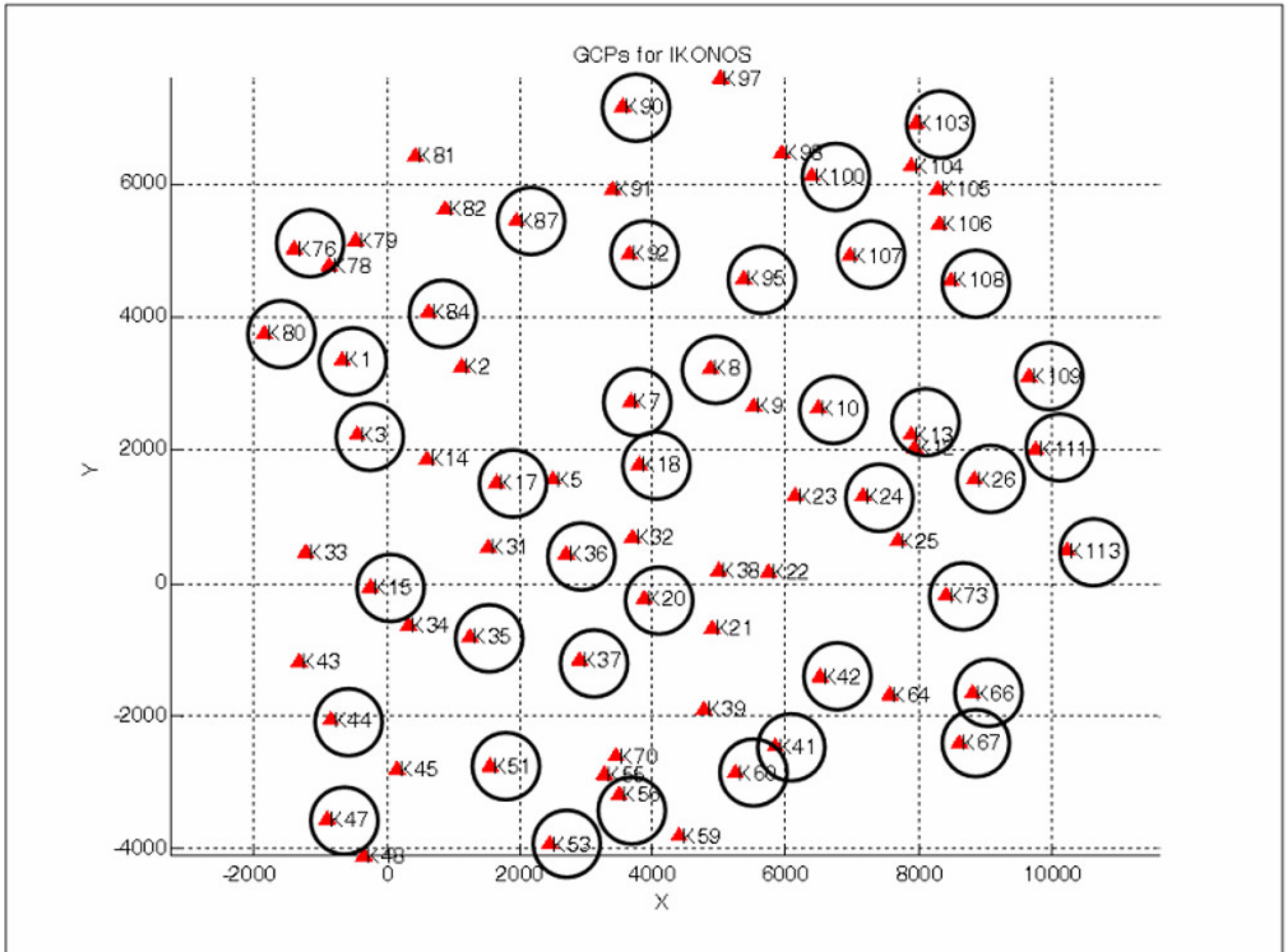
7 Ground Control Points

# GCP	# Frames	GPS / LIN / PATCH	$\hat{\sigma}_0$ (mm)	RMSE (m)			
				X	Y	Z	Total
7	0	NONE	0.005	1.442	1.608	3.290	3.936
	18	NONE	0.006	1.568	1.029	2.392	3.039
		LIN	0.005	1.738	1.130	1.722	2.696
		PATCH	0.004	1.516	1.025	1.774	2.549
		GPS	0.007	1.657	1.025	1.747	2.618
		GPS + LIN	0.005	1.783	1.132	1.724	2.726
		GPS + PATCH	0.004	1.578	1.024	1.792	2.598

138 Control Lines & 139 Control Patches

Scan line direction

Configuration of 40 GCP



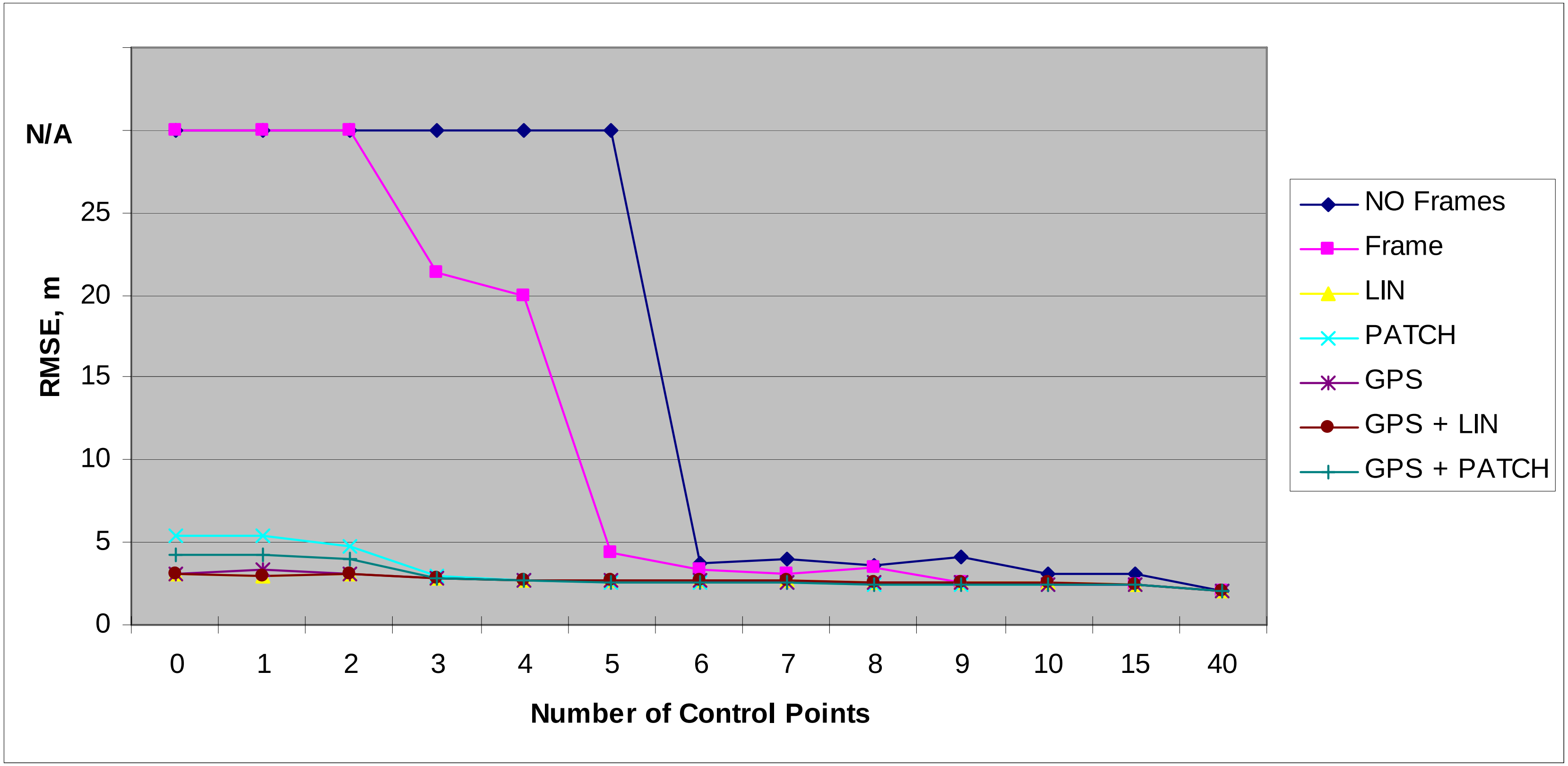
40 Ground Control Points

# GCP	# Frames	GPS / LIN / PATCH	$\hat{\sigma}_0$ (mm)	RMSE (m) X	RMSE (m) Y	RMSE (m) Z	Total
40	0	NONE	0.011	1.092	0.870	1.450	2.013
	18	NONE	0.008	1.129	0.863	1.528	2.087
		LIN	0.006	1.173	0.921	1.495	2.112
		PATCH	0.004	1.110	0.845	1.475	2.030
		GPS	0.008	1.122	0.859	1.563	2.107
		GPS + LIN	0.006	1.143	0.934	1.498	2.103
		GPS + PATCH	0.004	1.095	0.846	1.478	2.026

138 Control Lines & 139 Control Patches

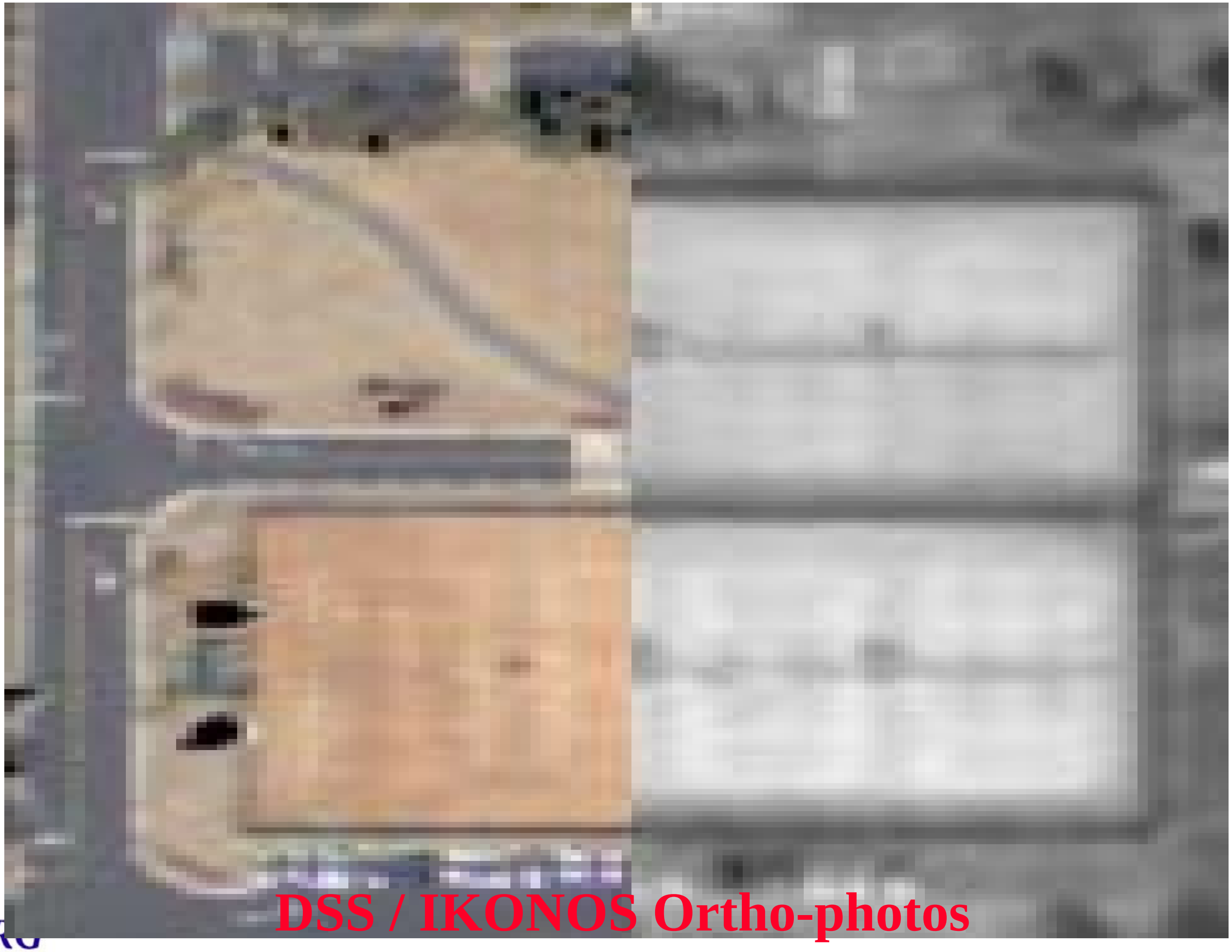
Scan line direction

MST: Experimental Results



MST: Experimental Results

MST: Experimental Results

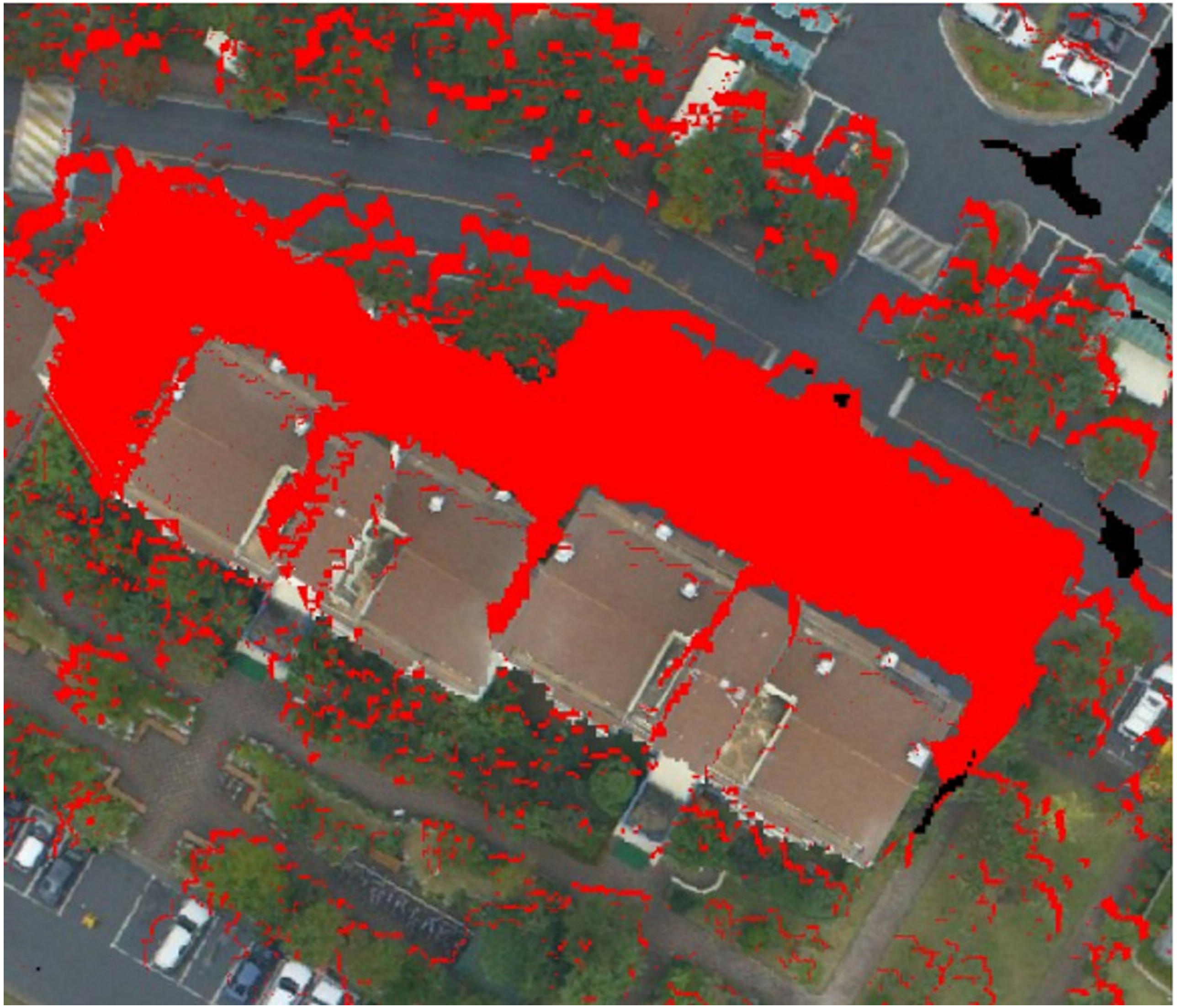


DSS / IKONOS Ortho-photos

Original Image

Ortho-Photo Generation

True Ortho-Photo Generation



MST: Experimental Results

Generated Ortho-photo

Differential Rectification

MST: Experimental Results

Generated Ortho-photo

True Ortho-photo

Concluding Remarks

- The introduced methodologies are successful in:
  - Using LIDAR features for photogrammetric geo-referencing.
    - Line-based and patch-based photogrammetric geo-referencing using control derived from LIDAR data.
  - Delivering a geo-referenced imagery of the same quality as point-based geo-referencing procedures.
  - Taking advantage of the synergistic characteristics of spatial data acquisition systems.
- The triangulation output can be used for the generation of 3-D perspective views.

Recommendations for Future Work

- Automated segmentation of LIDAR data to extract the patches and linear features.
- More investigation into using the outcome from the geo-referencing procedure for the verification of the system calibration.
- Utilize the raw LIDAR measurements in the patch-based photogrammetric geo-referencing.
  - Such a utilization will allow for LIDAR system calibration.
- Quality assurance and quality control procedures for LIDAR data.

3-D Perspective View