# MEDIUM-FORMAT DIGITAL CAMERAS:

## A STUDY INTO THE CALIBRATION, STABILITY ANALYSIS, AND INTEGRATION WITH HIGH RESOLUTION SATELLITE IMAGERY

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# Overview

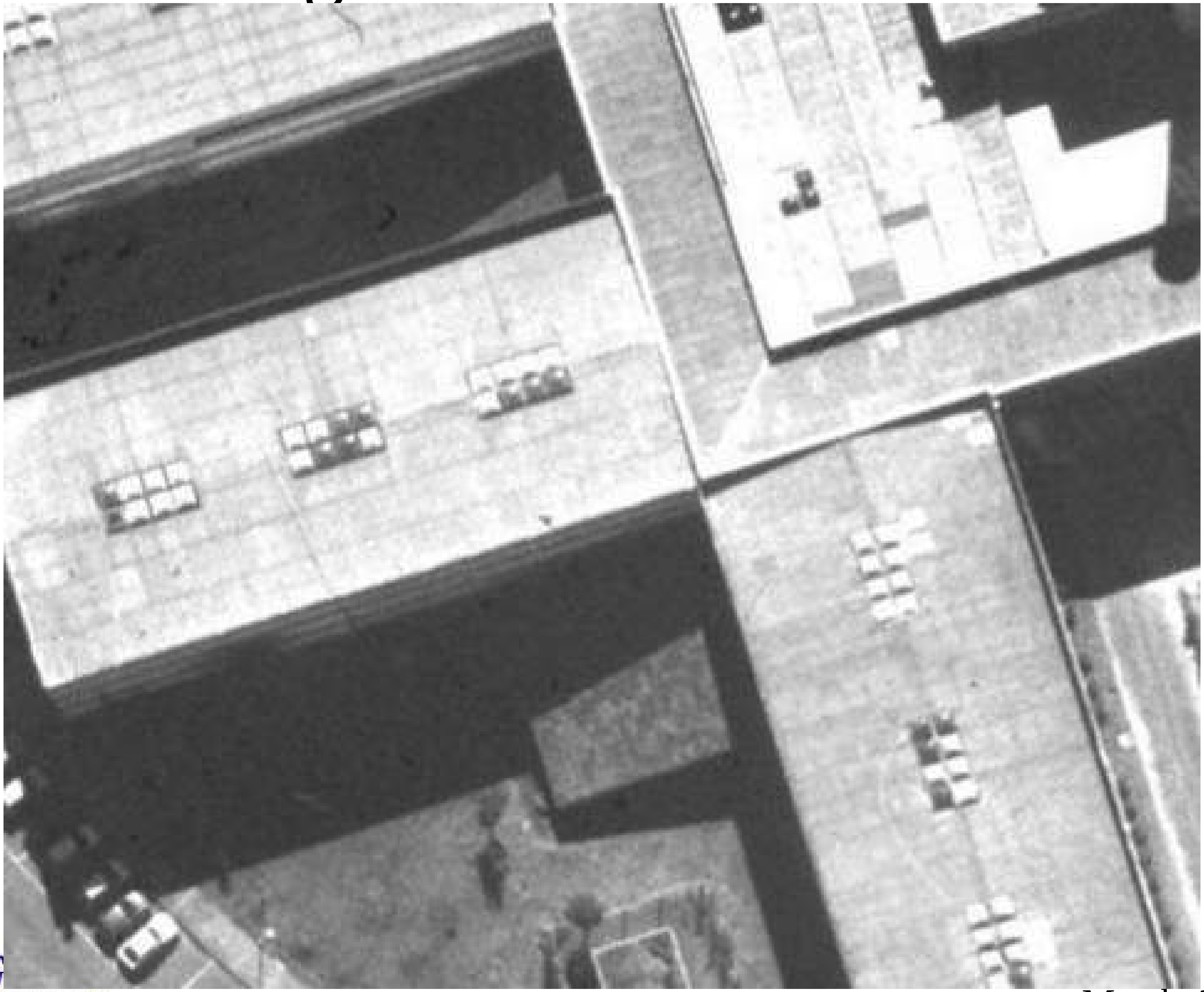
- Medium-format digital cameras: introduction.
- Camera Calibration
- Camera Stability Analysis
- Experimental Results
- Integration of Aerial and High Resolution Satellite Imagery

# Commercial Digital Cameras

Traditional Mapping Cameras

Medium Format Digital Cameras

# Analog Camera: WILD RC10



# Medium-Format Digital Cameras

SONY DSC F717

# MFDC Applications

- Aerial surveys of hurricane ravaged regions
- Modeling of 3D scenes
- Computer Vision
- Rapid Mapping

***The devastation in Ocean Springs, Miss., taken on Aug. 30, 2005, after Hurricane Katrina slammed the region (NOAA)***

# New Issues of Importance

- The growth of the field as well as the increase in the diversity of applications has numerous advantages

- However, new issues of concern are to be addressed

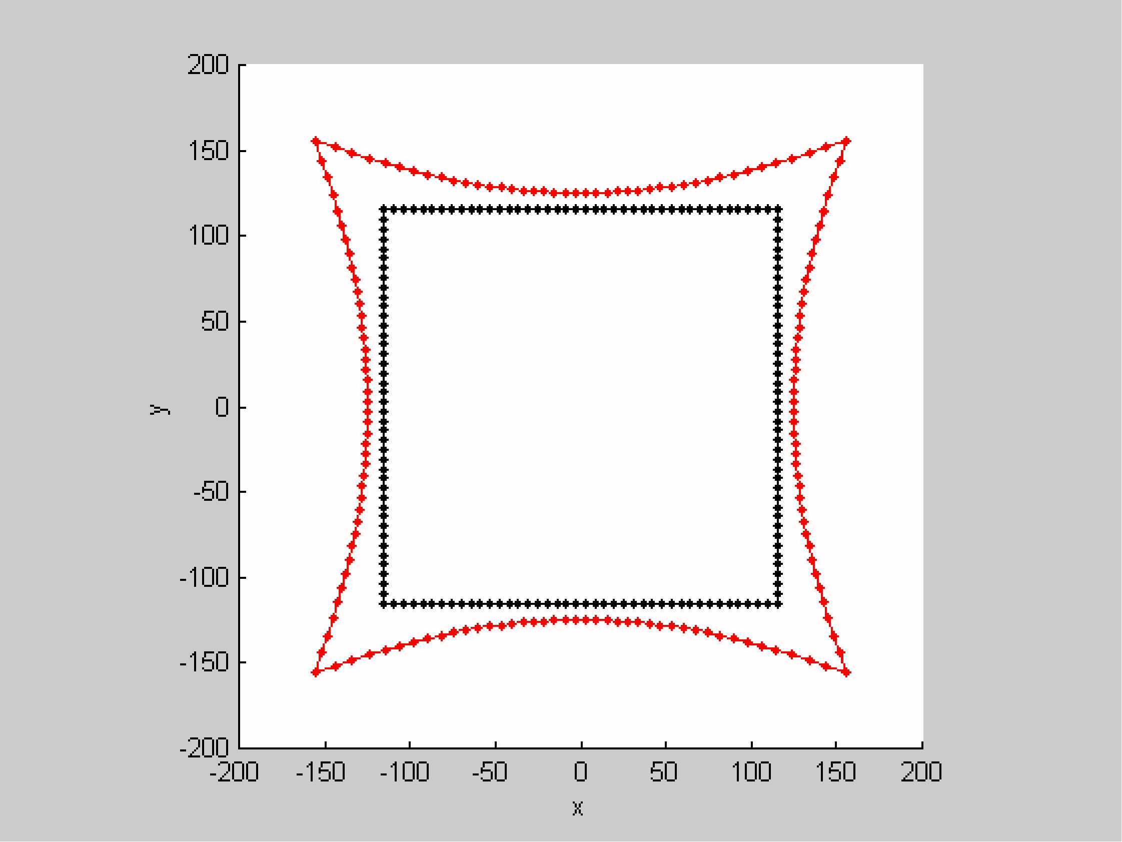
- Camera Calibration
  - Accurate determination of internal camera characteristics

- Stability Analysis
  - Confirm that the camera is stable over time

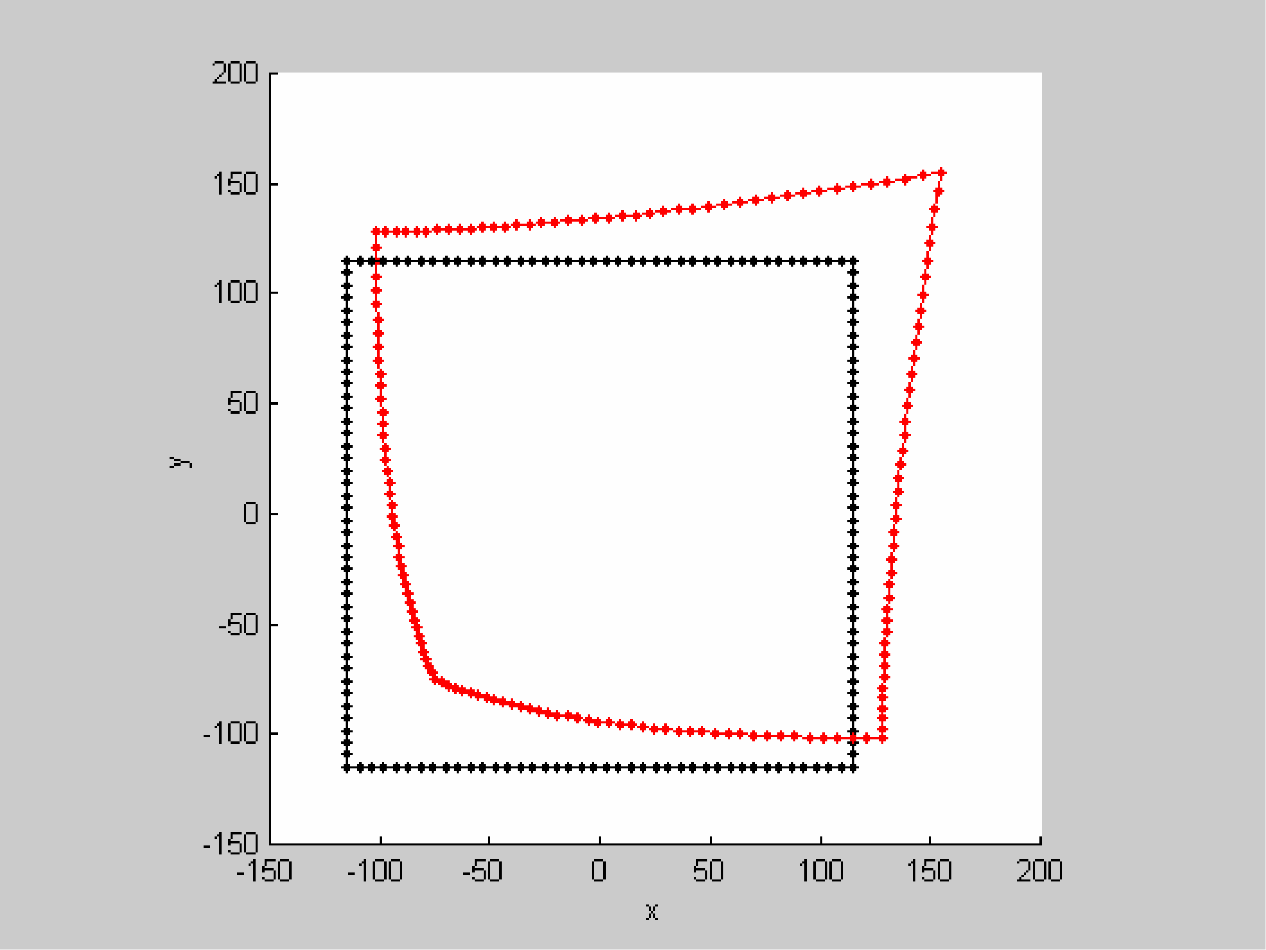
# Interior Orientation Parameters (IOP)

- Principal point coordinates ($x_p$, $y_p$).
- Principal distance (c).
- Distortion parameters:
  - Radial Lens Distortion (RLD).
  - De-centering Lens Distortion (DLD).
  - Affine Deformations (AD).
- The IOP are determined through a bundle adjustment with self-calibration procedure.
  - Point-based calibration.
  - Point & line-based calibration.

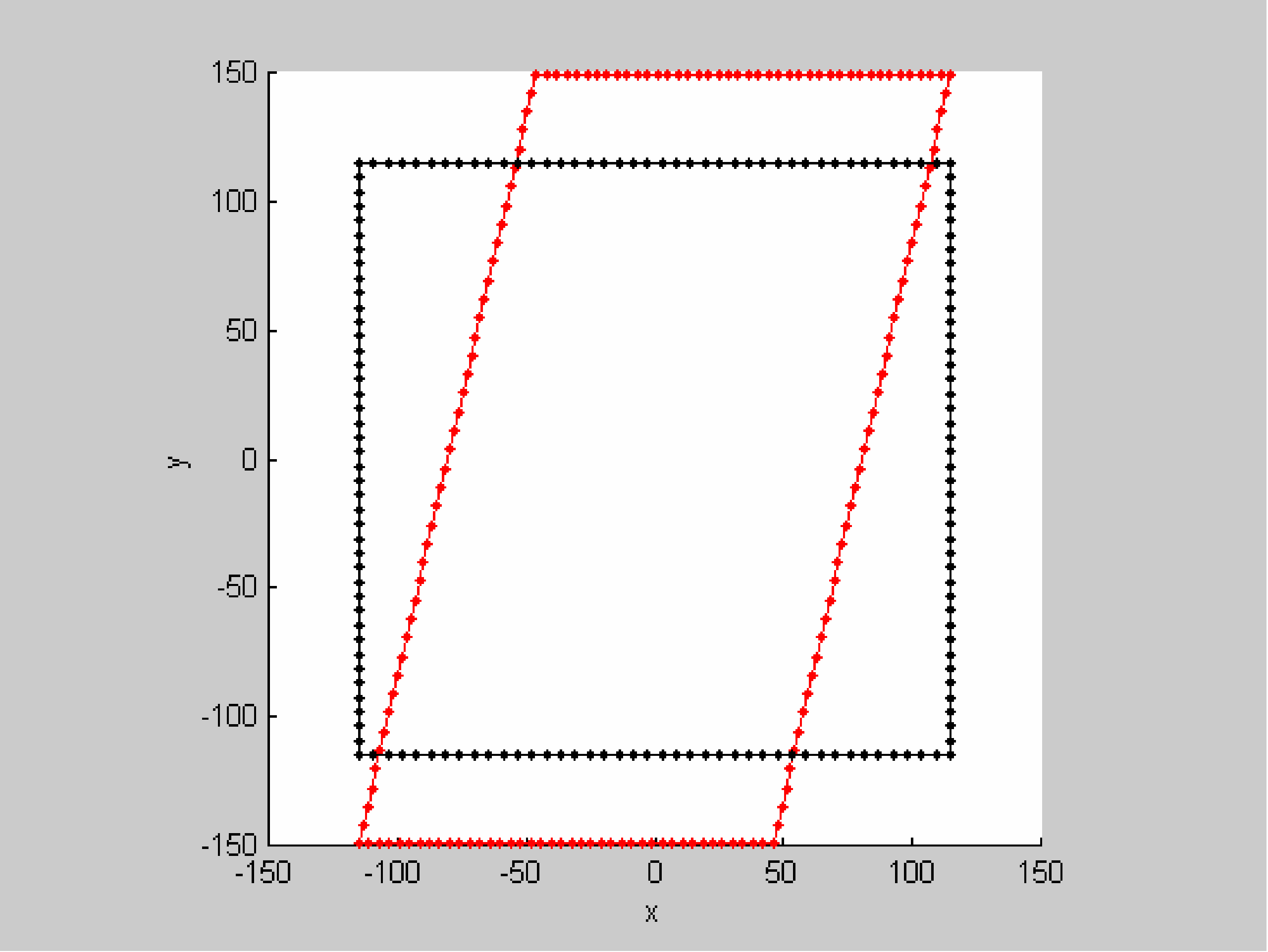
# Radial Lens Distortion (RLD)



# Decentric Lens Distortion (DLD)



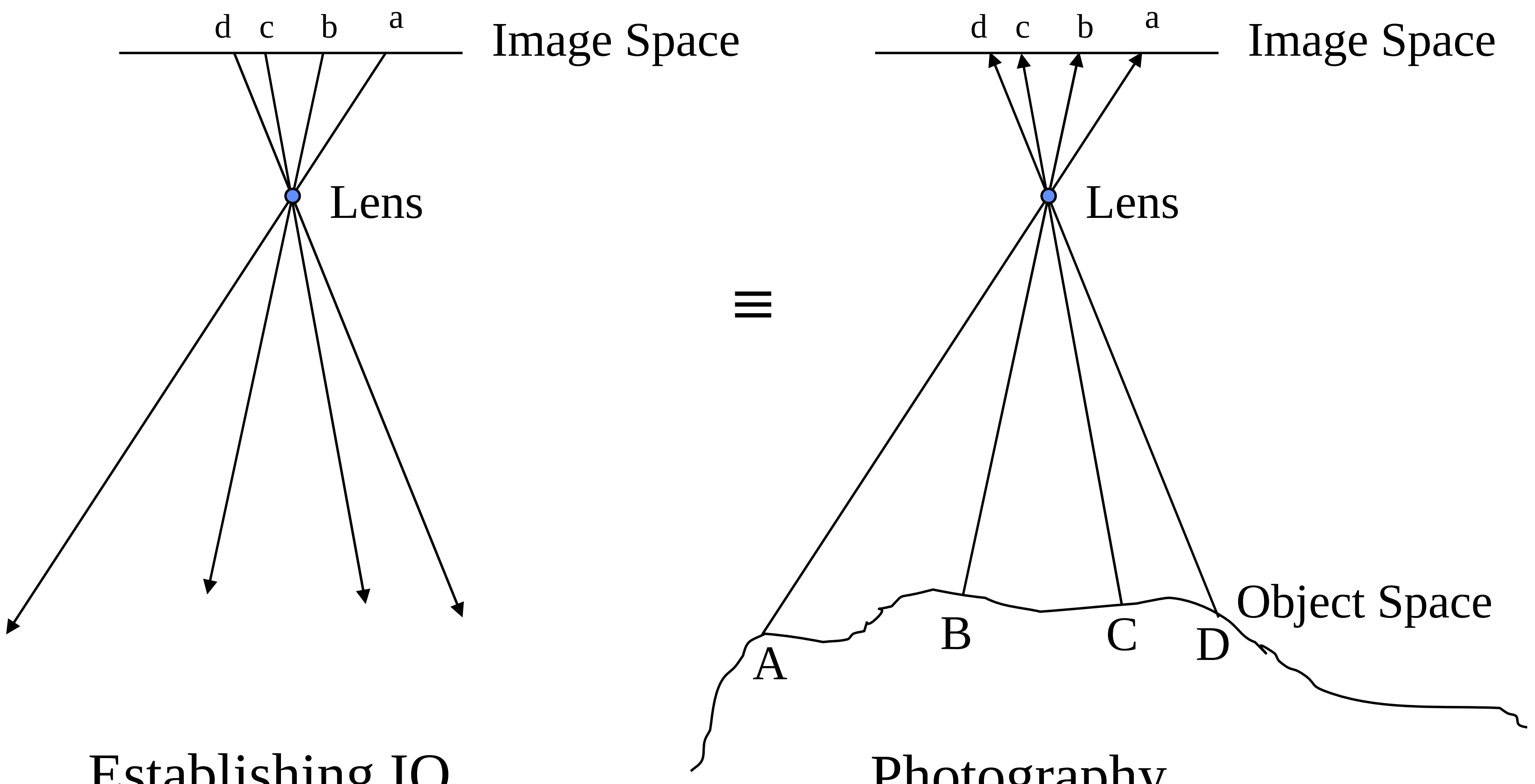
# Affine Deformations (AD)



# Camera Calibration

- Calibration parameters describe the internal characteristics of the implemented camera.

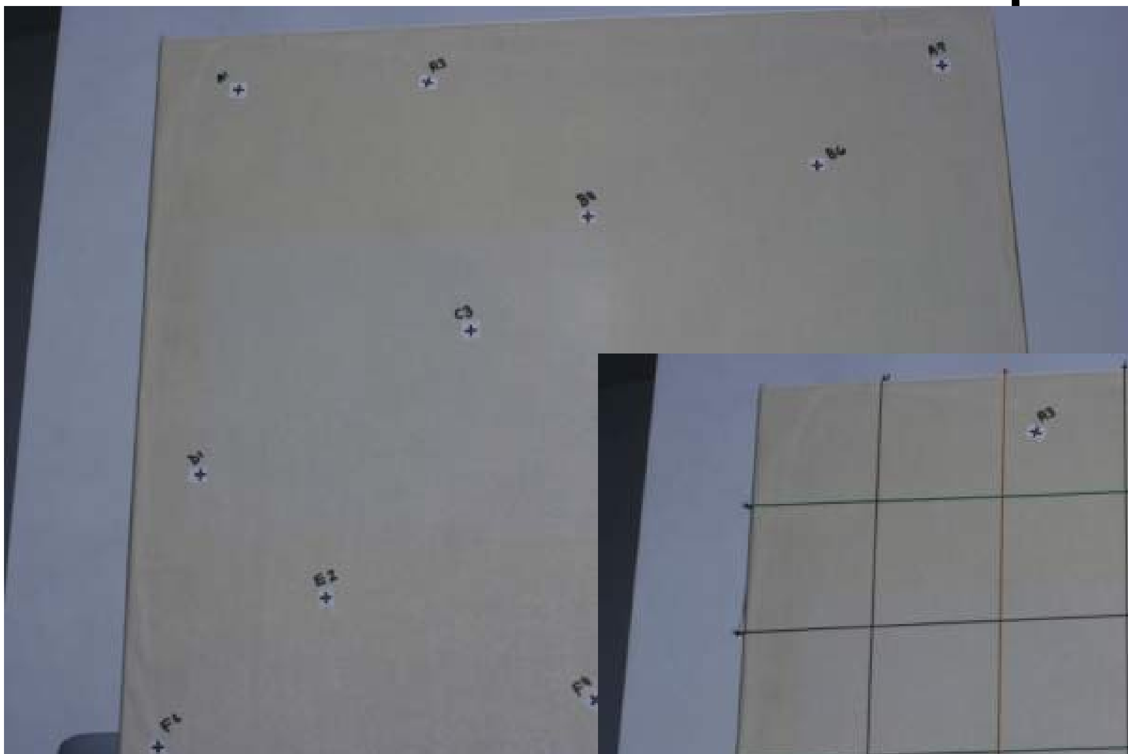
# Interior Orientation




Establishing IO

Photography

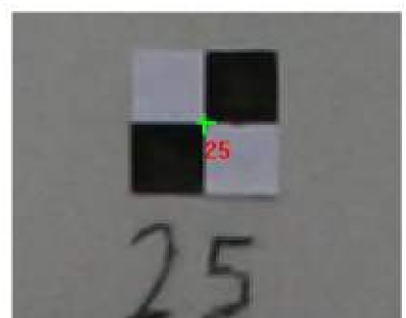
# Traditional Versus Proposed Test Field

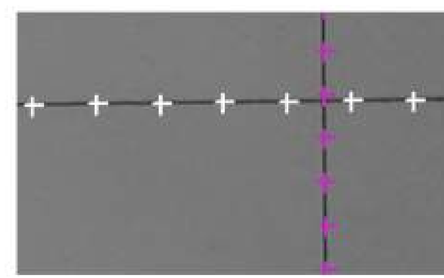


# Building the Calibration Test Field

# Automated Feature Extraction

To simplify the often lengthy procedure of of manual image coordinate measurement, an automated procedure is introduced for the extraction of point targets and line features.



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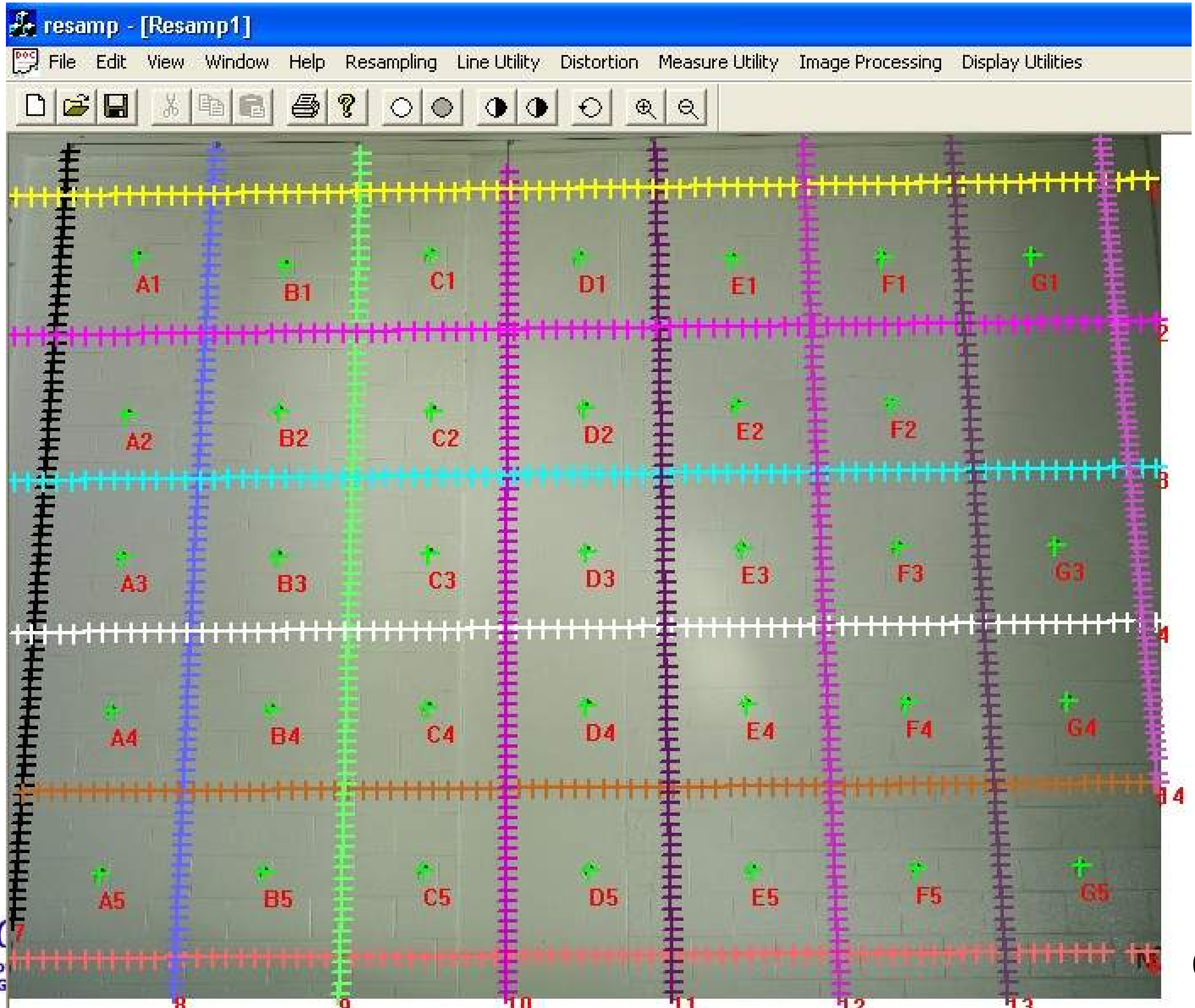
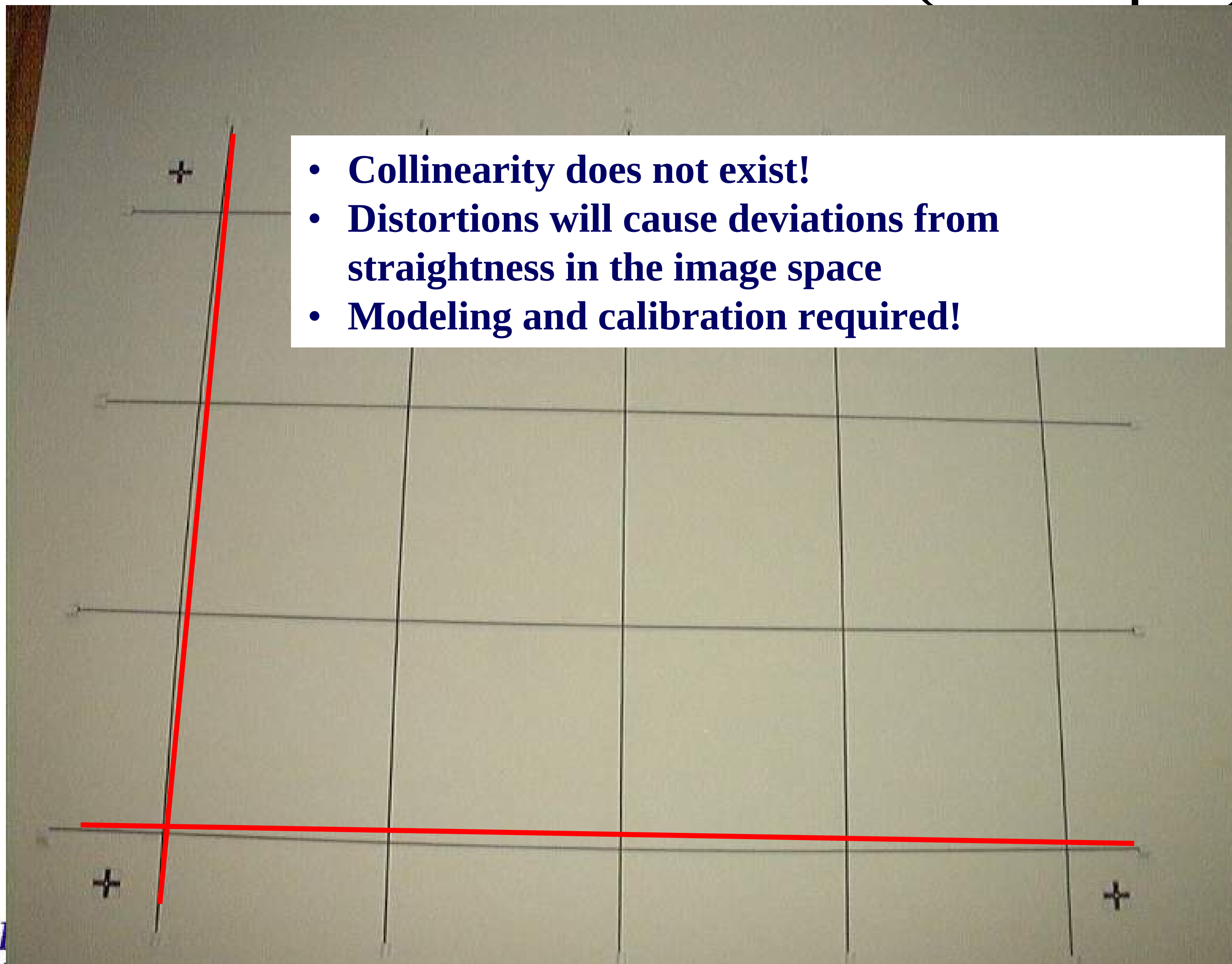
# Measurement Environment



# Evaluation Criteria

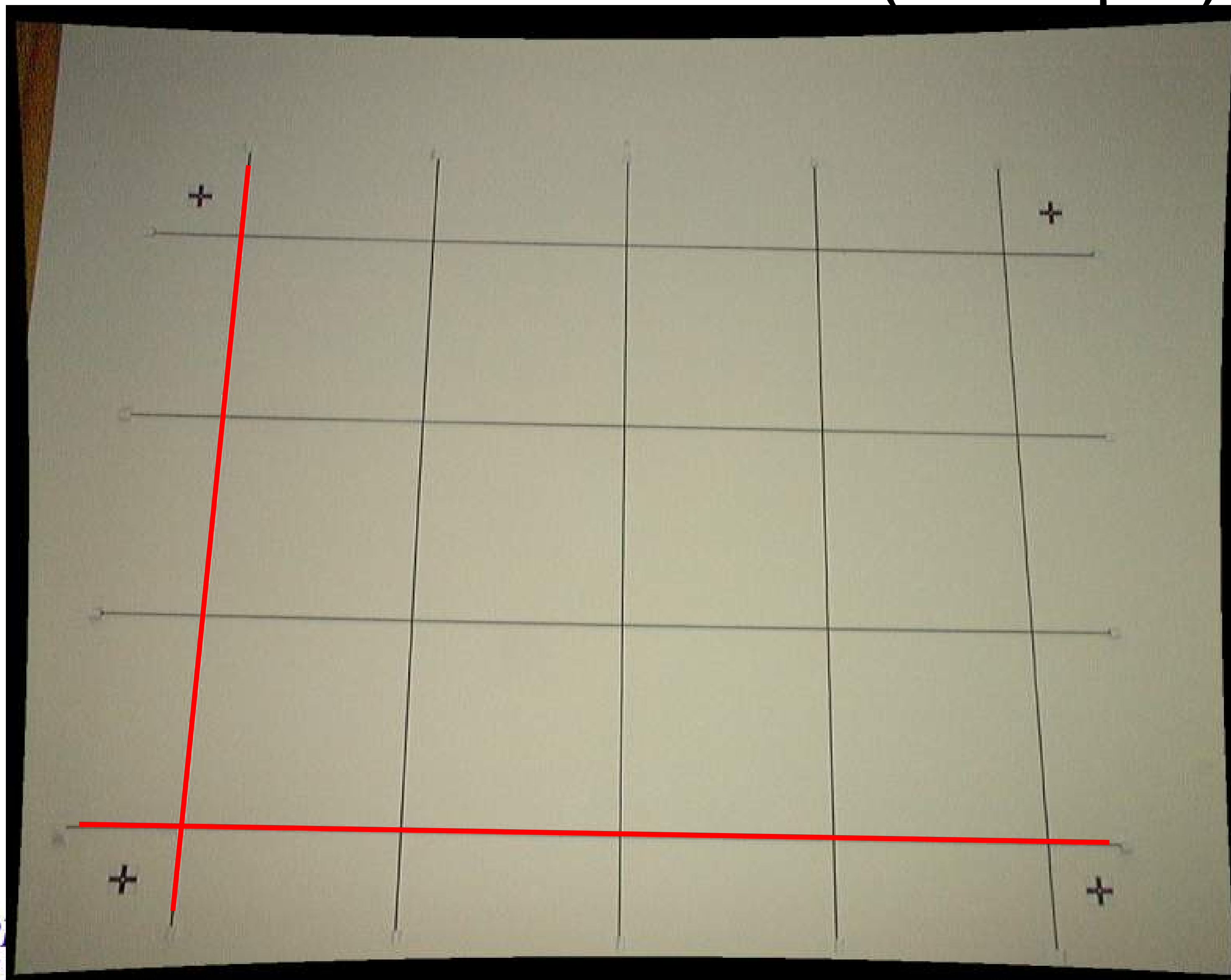
- Recovery of straightness after calibration and distortion removal.
  - This is conducted for point and line-based calibration.
- Check point analysis.
  - RMSE analysis of surveyed targets (30 targets used as check points).

# Before Distortion Removal (Example)



- **Collinearity does not exist!**
- **Distortions will cause deviations from straightness in the image space**
- **Modeling and calibration required!**

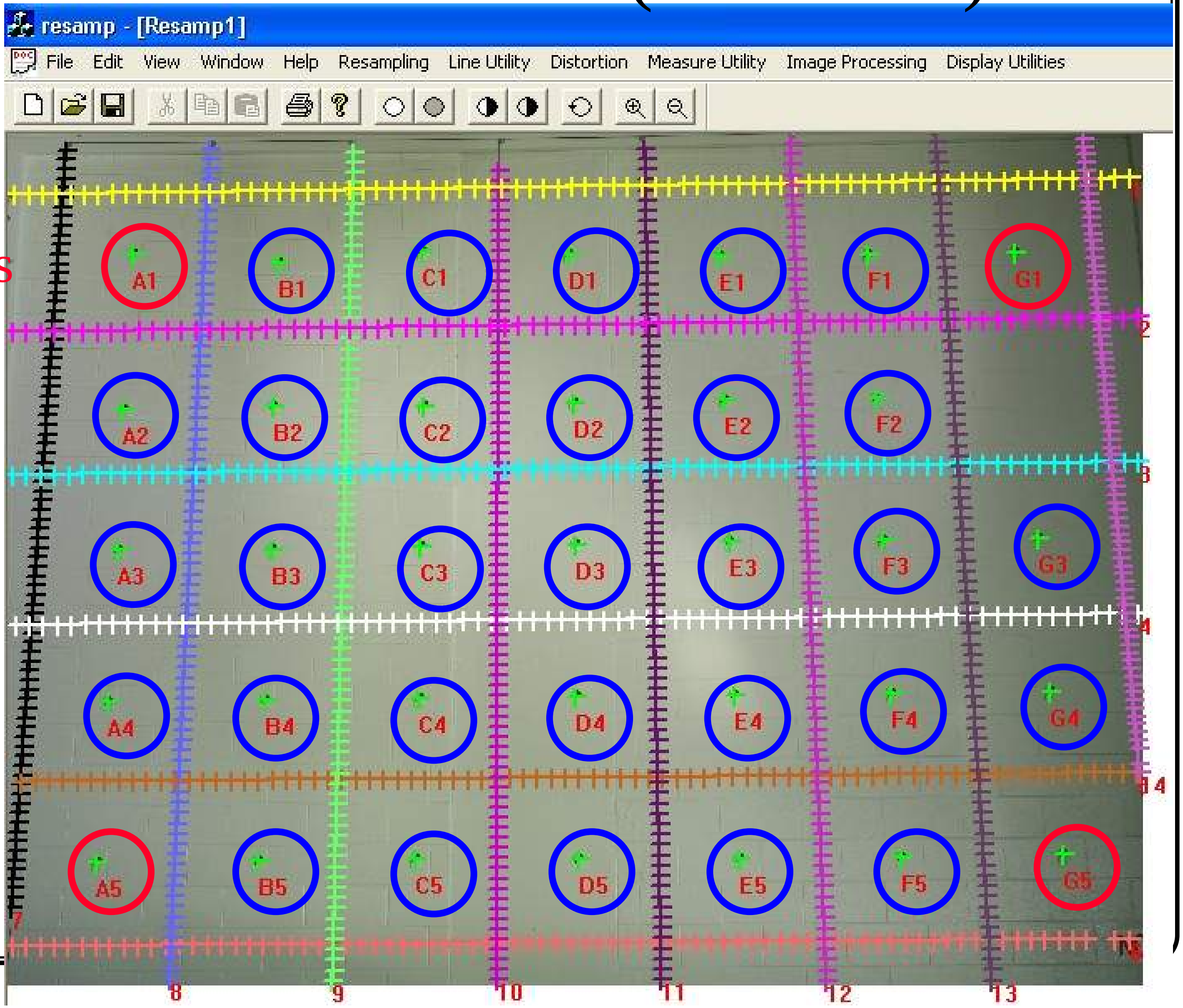
# After Distortion Removal (Example)



# Line-Based Calibration (DAC 101)

Control Points

Tie Points

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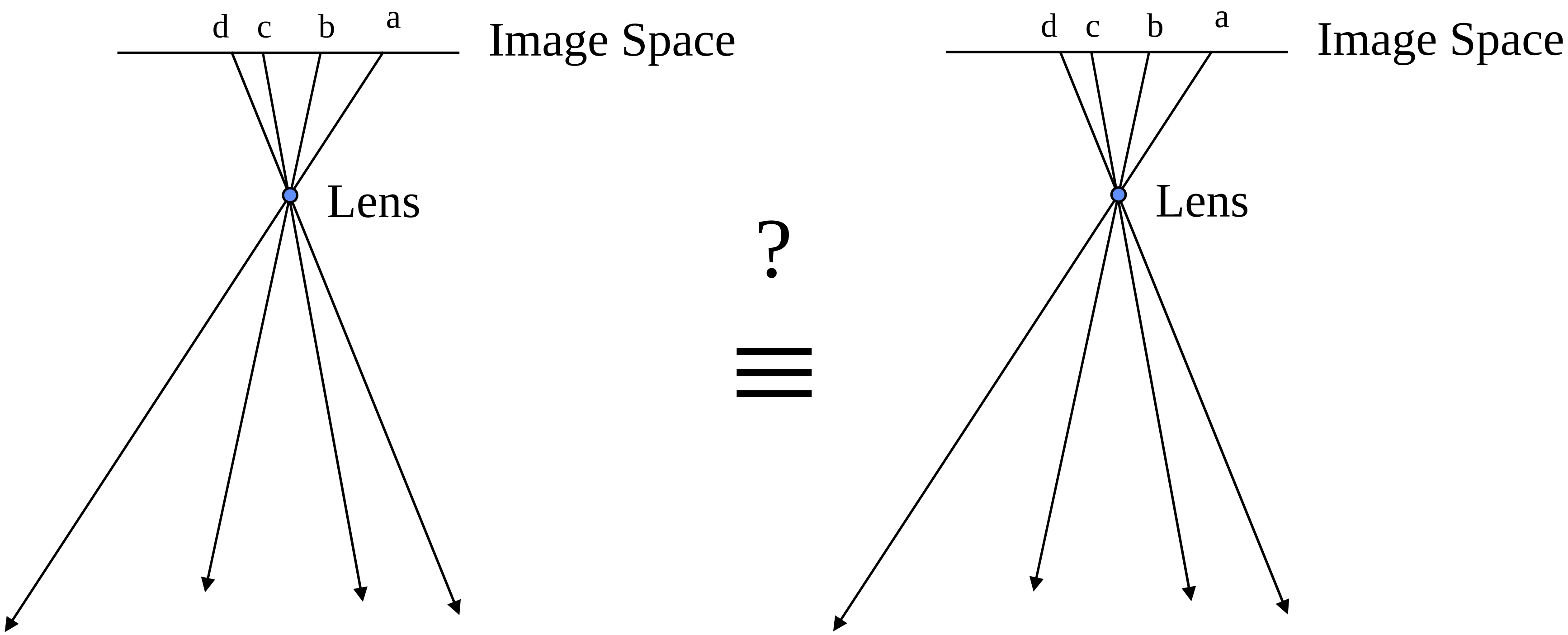
# Check Point Analysis (DAC 101)

- February 8, 2006 ($IOP_I$):
  - no of points = 30
  - RMSE (X) = 0.00035 m
  - RMSE (Y) = 0.00029 m
  - RMSE (Z) = 0.00082 m
- February 9, 2006 ($IOP_{II}$):
  - no of points = 30
  - RMSE (X) = 0.00027 m
  - RMSE (Y) = 0.00046 m
  - RMSE (Z) = 0.00064 m

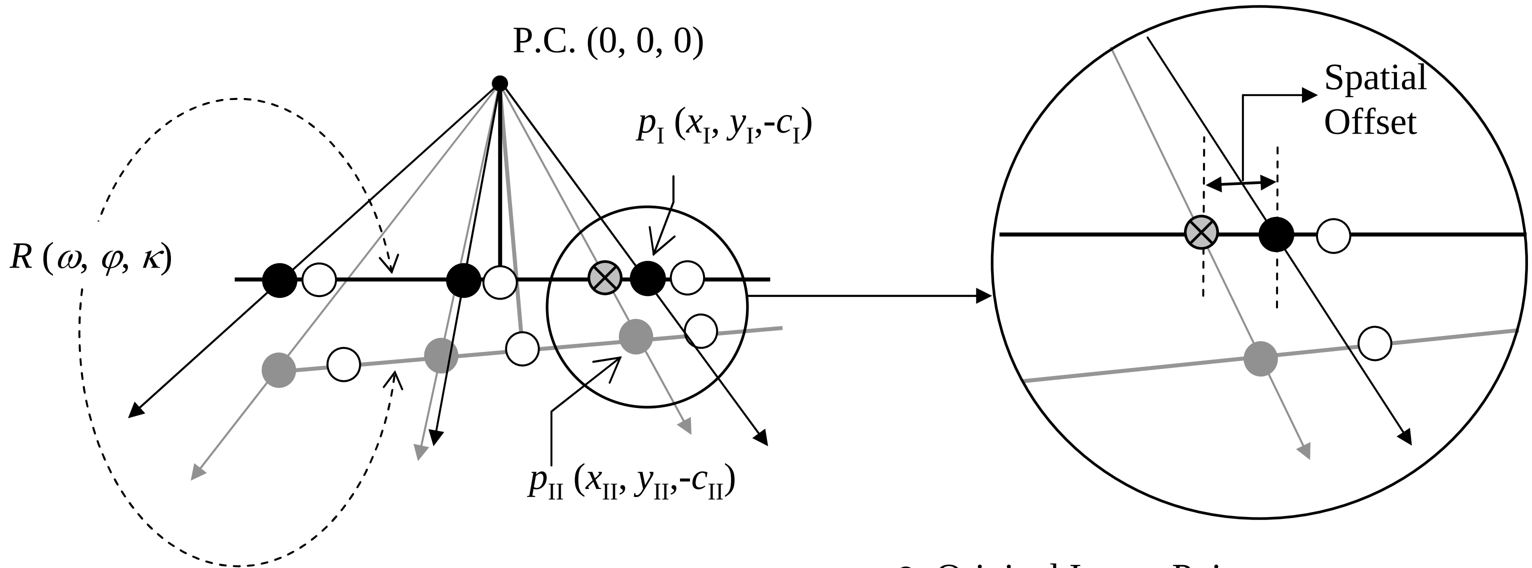
# Stability Analysis




Reconstructed bundle using $IOP_I$ Reconstructed bundle using $IOP_{II}$

# Stability Analysis

- Rotation (ROT)
  - Same perspective center (no shift allowed)
  - Rotation allowed




○ Original Image Points

● Distortion-free Grid Point using $IOP_I$

● Distortion-free Grid Point using $IOP_{II}$

⊗ Projected Grid Point of $IOP_{II}$

# Stability Analysis (DAC 101)

- Stability Analysis Results:
- $\sigma_o$: 0.0043 mm (Acceptable)
  - $\omega$: 95"
  - $\varphi$: 122"
  - $\kappa$: -3"
- Conclusion: The bundles defined by $IOP_I$ and $IOP_{II}$ are similar.
- The camera is deemed stable between the two calibration sessions.

Pixel Size = 9 µm

# MFDC – DAC101 Analysis

Digital Aerial Camera (DAC 101), built by Selkirk Remote Sensing Ltd., Vancouver, BC

Flight mission in BC (Jan. 2007)

# MFDC – DAC101 Analysis

DAC101 Stability results

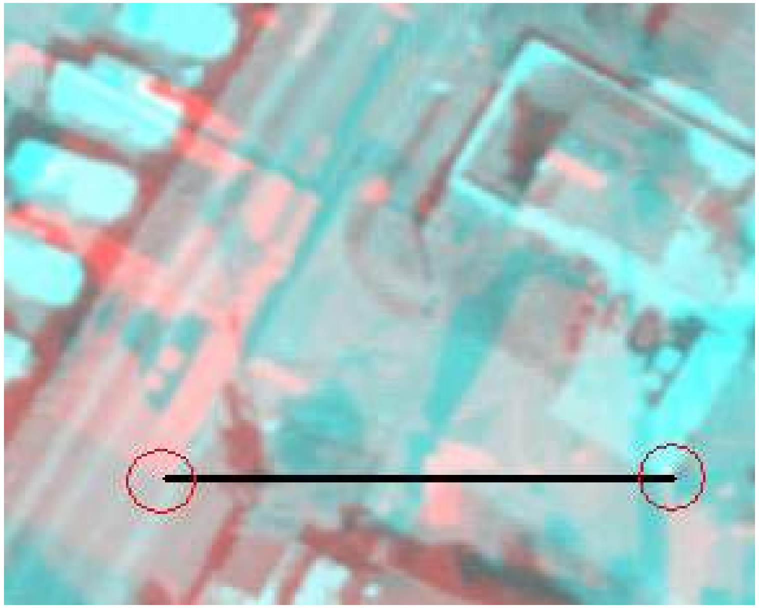
| | |
|---|---|
| Feb8_2006 vs. Mar_2007 | RMSE = 0.005852 |
| Feb9_2006 vs. Mar_2007 | RMSE = 0.006786 |
| Mar2_2006 vs. Mar_2007 | RMSE = 0.007632 |
| Apr_2006 vs. Mar_2007 | RMSE = 0.009127 |

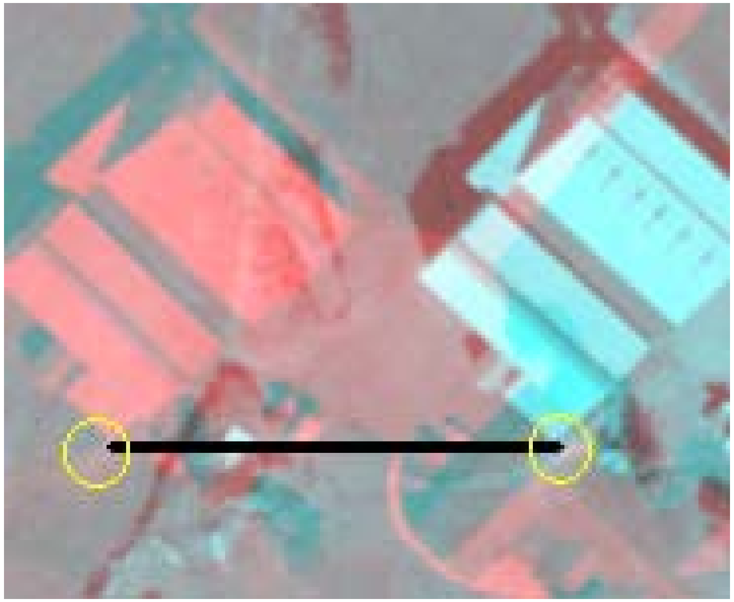
Y-Parallax (in pixels) in imagery collected from the DAC101

| | **Stereopair 1** | **Stereopair 2** | **Stereopair 3** | **Stereopair 4** |
|---|---|---|---|---|
| **Mininum y-parallax** | 0.06995 | 0.02568 | 0.03347 | 0.01674 |
| **Maxiumum y-parallax** | 2.2636 | 1.00419 | 1.51883 | 1.12511 |
| **Mean** | 0.5603 | 0.40278 | 0.57740 | 0.54501 |
| **Standard Deviation** | 0.6228 | 0.26875 | 0.38375 | 0.42966 |

# MFDC – DAC101 Analysis

DAC101 Stereopairs: observe the lack of y-parallax





# Medium-Format Digital Cameras

- Established a calibration procedure using point and linear features.
- Established meaningful measures for evaluating the stability of given camera from temporal calibration results.
- Developed specifications for regulating the use of medium-format digital cameras.
  - Incorporated feedback from the mapping industry.

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# Multi-Sensor Photogrammetric Triangulation:

## Integration of Aerial and High Resolution Satellite Imagery

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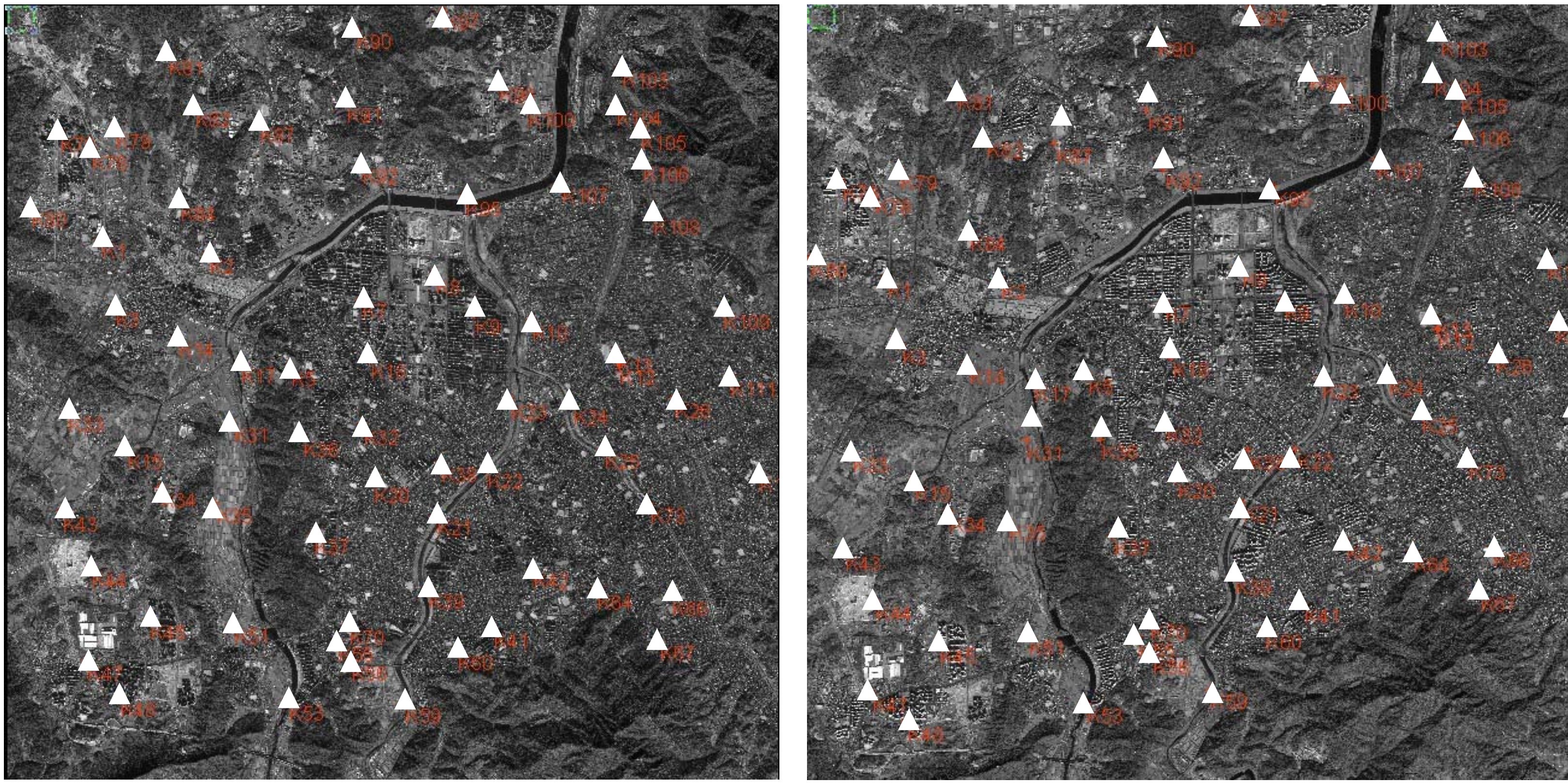
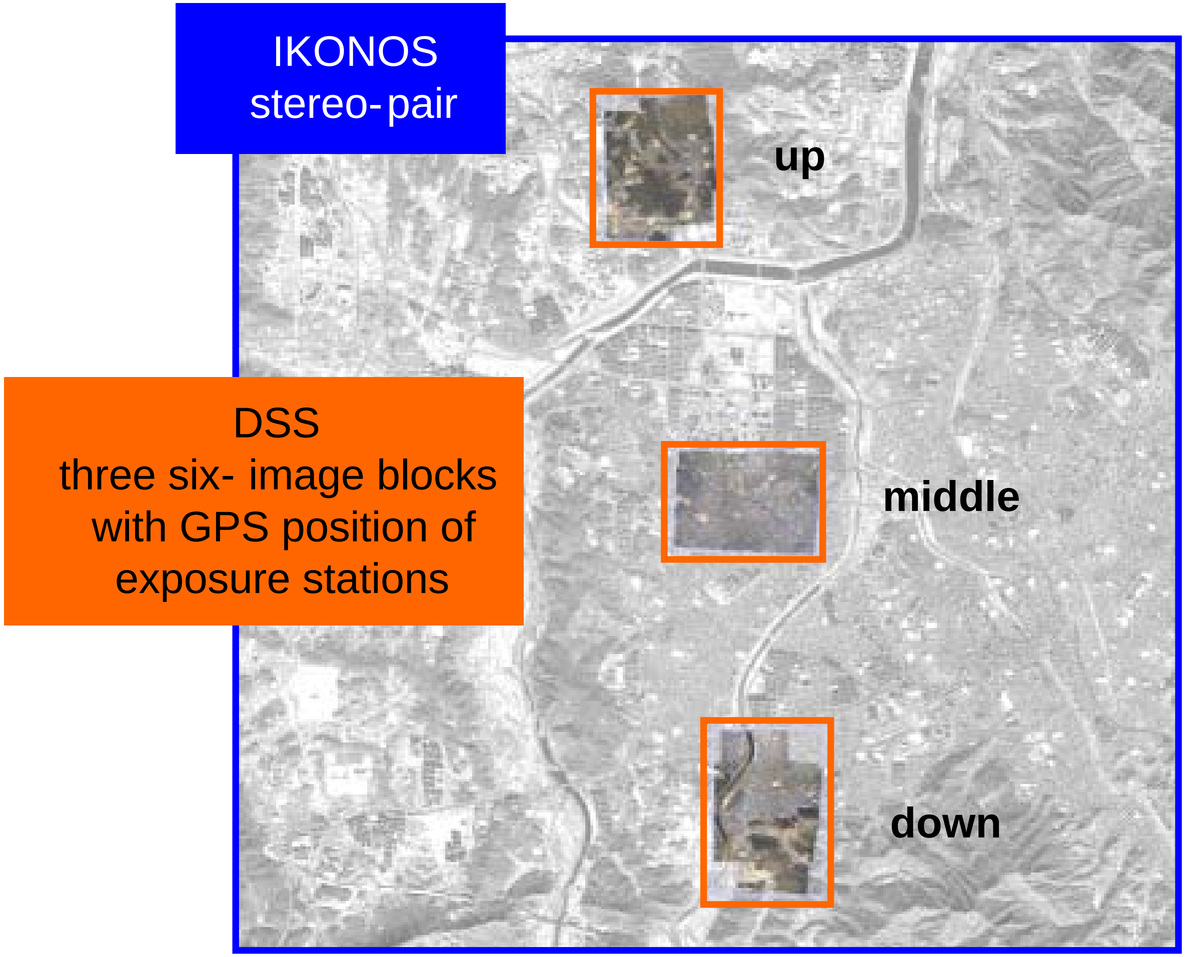
# Experimental Results: Dataset



IKONOS scenes and GCP layout over Daejeon, Korea

# Experimental Results: Dataset



# IKONOS + DSS + GPS

| # of GCPs | IKONOS only | IKONOS + 18 DSS Frame images | |
|---|---|---|---|
| | Control Points Only | Control Points Only | Control Plus DSS GPS |
| 0 | N/A | N/A | 3.066 |
| 1 | N/A | N/A | 3.368 |
| 2 | N/A | N/A | 3.082 |
| 3 | N/A | 21.322 | 2.863 |
| 4 | N/A | 19.956 | 2.759 |
| 5 | N/A | 4.342 | 2.727 |
| 6 | 3.668 | 3.352 | 2.702 |
| 7 | 3.936 | 3.039 | 2.618 |
| 8 | 3.591 | 3.417 | 2.579 |
| 9 | 4.079 | 2.543 | 2.513 |
| 10 | 3.068 | 2.499 | 2.501 |
| 15 | 3.152 | 2.413 | 2.463 |
| 40 | 2.013 | 2.087 | 2.107 |

# Concluding Remarks

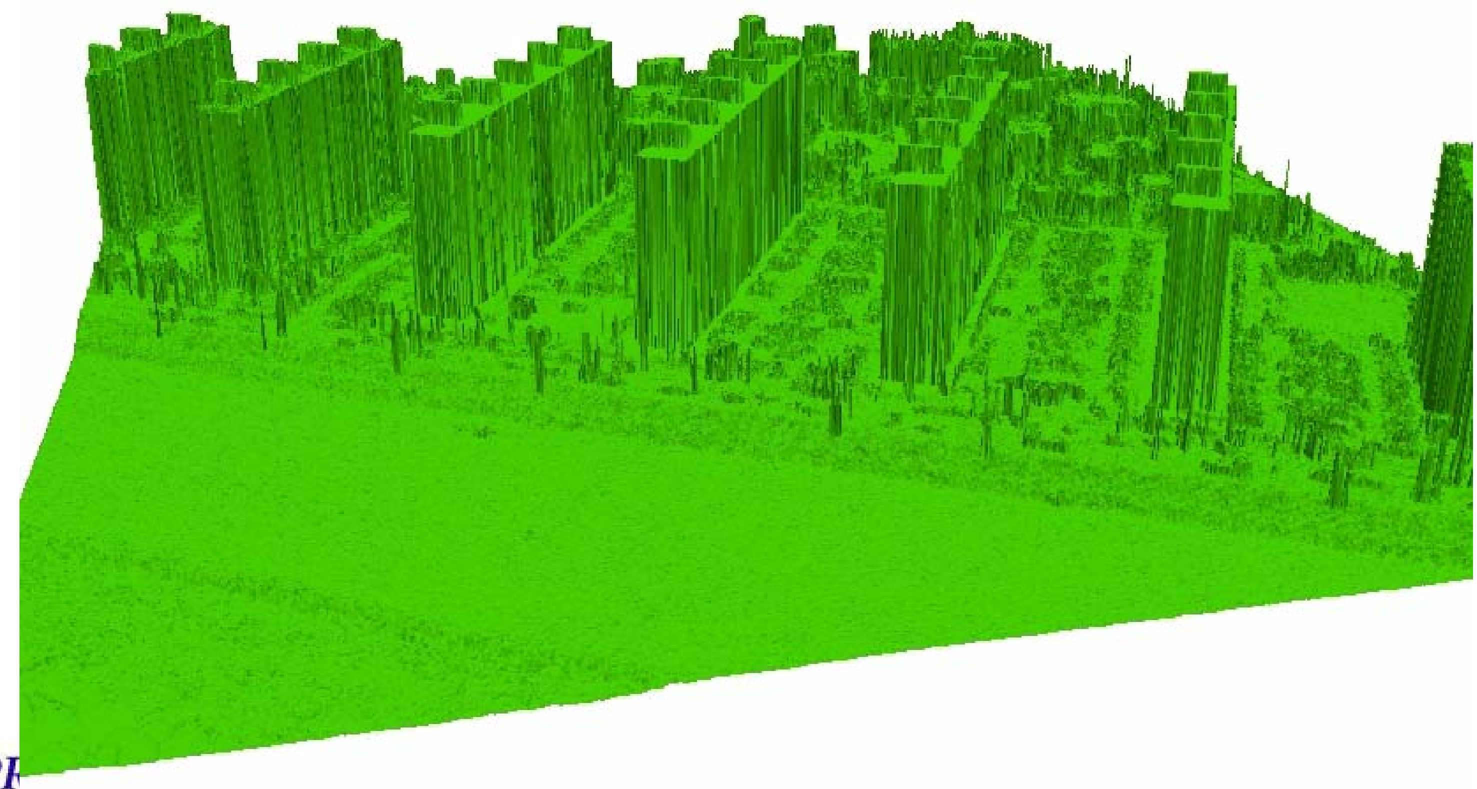
- We have a multi-sensor & multi-primitive triangulation environment.
  - Sensors: Line cameras, frame cameras, GPS/INS, and LIDAR.
  - Primitives: points, lines, and areal features.
- Integrating multi-sensory data in a single triangulation environment will help in:
  - Reducing the control requirements while maintaining the reconstruction accuracy.
- The output from the triangulation is useful for orthophoto generation and change detection applications.

# Integration of Lidar and Imagery

Input Imagery (# 27)

# Methodologies and Procedures

LIDAR DSM + DBM (Four Buildings)



# Methodologies and Procedures

DBM (four buildings) has been incorporated