Automatic Co-registration & Change Detection Between Multiple Data Sets

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Overview

- Introduction.
- Suggested Algorithm: Modified Iterated Hough Transform (MIHT) for robust parameter estimation.
- Application:
  - Single Photo Resection (SPR).
- Conclusions & Future Work.
- Other Research Activities.

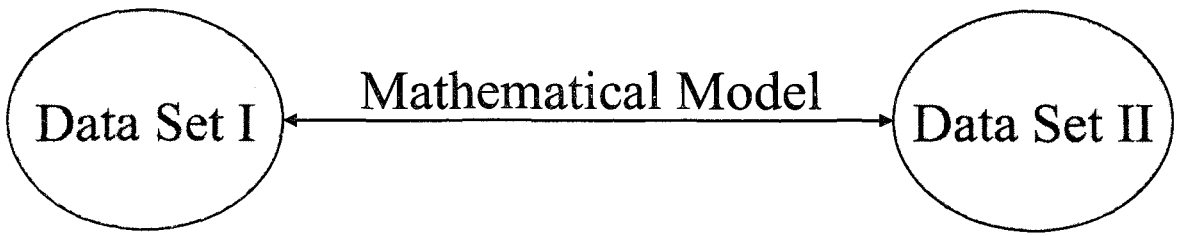
Introduction

- Recent technical advances have produced a variety of sensors:
  - Digital frame cameras, line cameras.
    - Optical, multi-spectral & hyper-spectral.
  - Ranging sensors (e.g. radar and laser systems).
  - Navigation sensors (e.g. GPS/INS).
- Each data set provides unique information about the area of interest.
- Co-registration of data/information collected by these sensors is one of the major problems facing the mapping community.

Introduction

- Co-registration activities rely on parameter estimation using conjugate entities in two data sets.
  - Relative Orientation.
  - Absolute Orientation.
  - Single Photo Resection.
  - Map Conflation.
- Conjugate Entities (manually) + Mathematical Model → Estimated Parameters.
- On the other hand, having the parameters relating the two data sets improves our ability to automatically find conjugate entities.

New Approach for Solving the Co-registration Problem



- Problem:
  - We need to solve for the parameters involved in the transformation between the two data sets.
  - The correspondence is not known.
- Solution:
  - Modified Iterated Hough Transform (MIHT) for Robust Parameters Estimation.

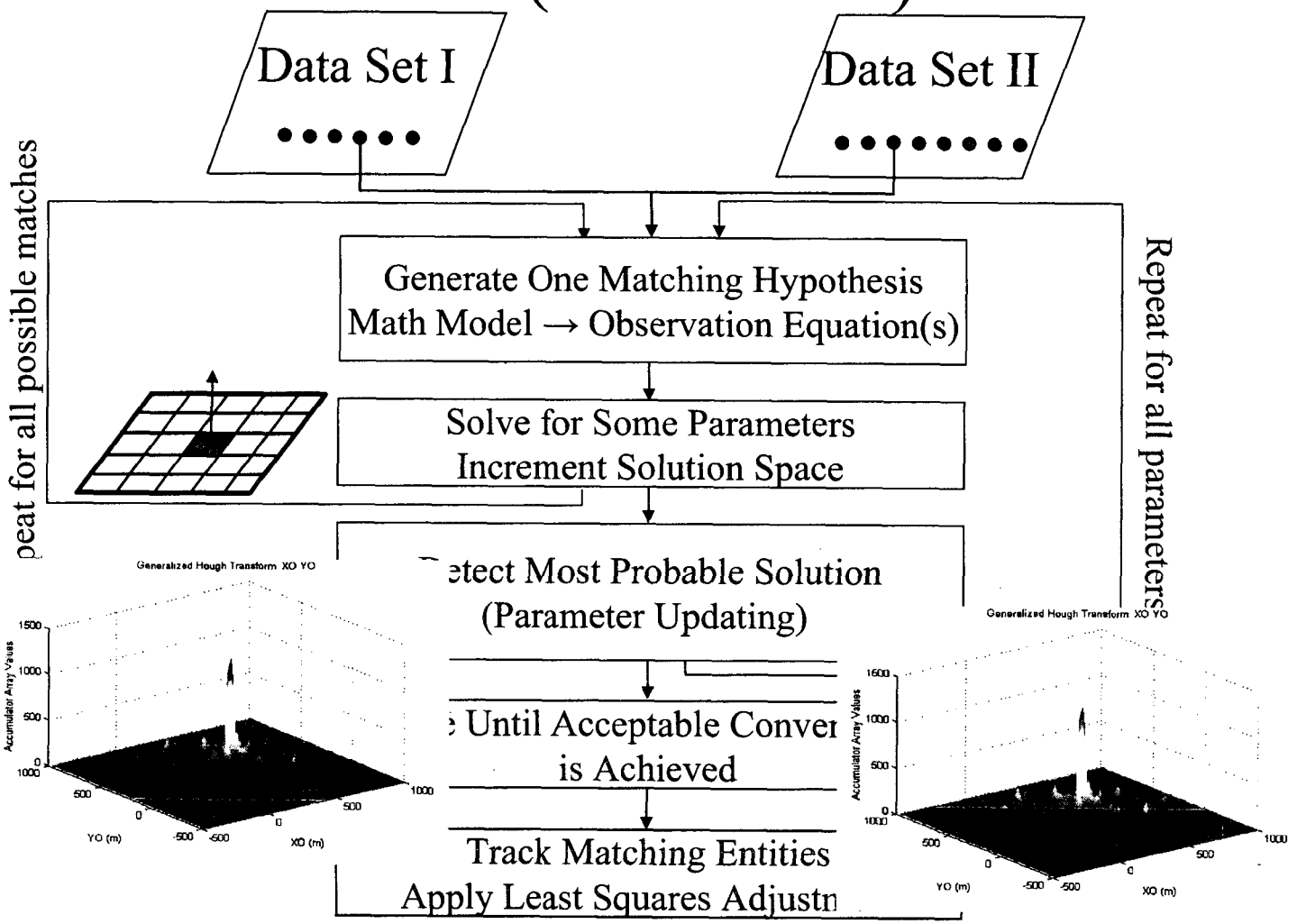
MIHT
Potential Applications

- Single Photo Resection:
  - **Data set 1:** Extracted edge pixels or line segments in image space.
  - **Data set 2:** 3-D object space points or line segments along linear features.
  - **Mathematical model:** The collinearity or coplanarity equations.
- Automatic Relative Orientation:
  - **Data set 1:** Extracted edge/feature pixels from the left image.
  - **Data set 2:** Extracted edge /feature pixels from the right image.
  - **Mathematical model:** coplanarity condition.
- Surface Matching:
  - **Data set 1:** 3-D points in one coordinate frame.
  - **Data set 2:** Surface patches in another coordinate frame.
  - **Mathematical model:** coordinate system transformation with coplanarity constraint.

Sequential Vs. Simultaneous Parameter Estimation

- Let's assume that there are:
  - **n** entities in the first data set (e.g., 20).
  - **m** entities in the second data set (e.g., 10).
  - **p** pairings needed to solve for the parameters (e.g., 3).
- First Alternative: Solving for all the involved parameters **simultaneously**.
  - # of combinations = (nm)! / {p! (nm - p)!} (1,313,400).
  - Large memory requirements & Inefficient.
- **Second Alternative**: Solving for the involved parameters **sequentially**.
  - (nm) combinations at a time (200).
  - More convenient

MIHT (Flow Chart)



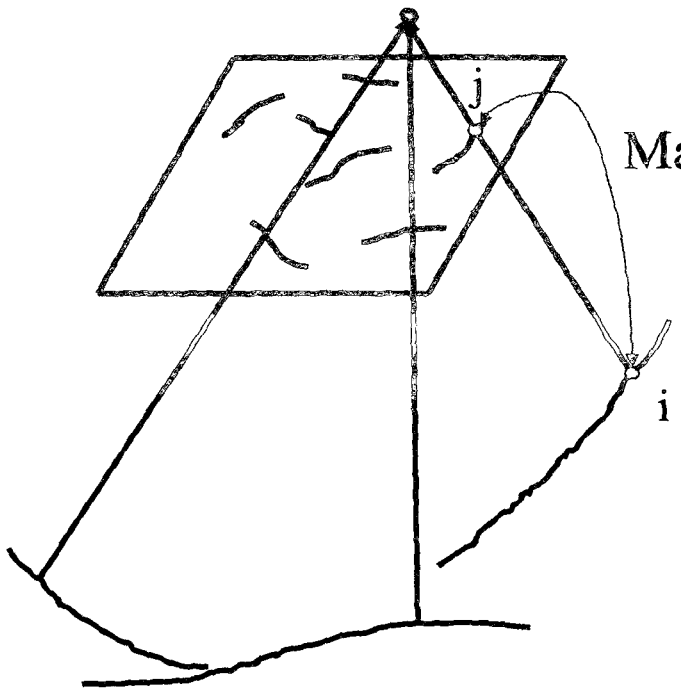
Single Photo Resection
&
Change Detection

- Control (Free-form) Linear Features.

Objectives

- **Data Integration:**
  - Combine data from terrestrial Mobile Mapping Systems (MMS) - e.g., the GPSVan, existing GIS database and aerial imagery.
- **Single Photo Resection (Geo-referencing):**
  - Free-form control linear features are used for determining the Exterior Orientation Parameters (EOP) of the aerial imagery.

Single Photo Resection / Point Model



Matching Hypothesis

$$x_j = -c\,\frac{r_{11}\,(X_i - X_o) + r_{21}\,(Y_i - Y_o) + r_{31}\,(Z_i - Z_o)}{r_{13}\,(X_i - X_o) + r_{23}\,(Y_i - Y_o) + r_{33}\,(Z_i - Z_o)}$$

$$y_j = -c\,\frac{r_{12}\,(X_i - X_o) + r_{22}\,(Y_i - Y_o) + r_{32}\,(Z_i - Z_o)}{r_{13}\,(X_i - X_o) + r_{23}\,(Y_i - Y_o) + r_{33}\,(Z_i - Z_o)}$$

Sequential Parameter Estimation

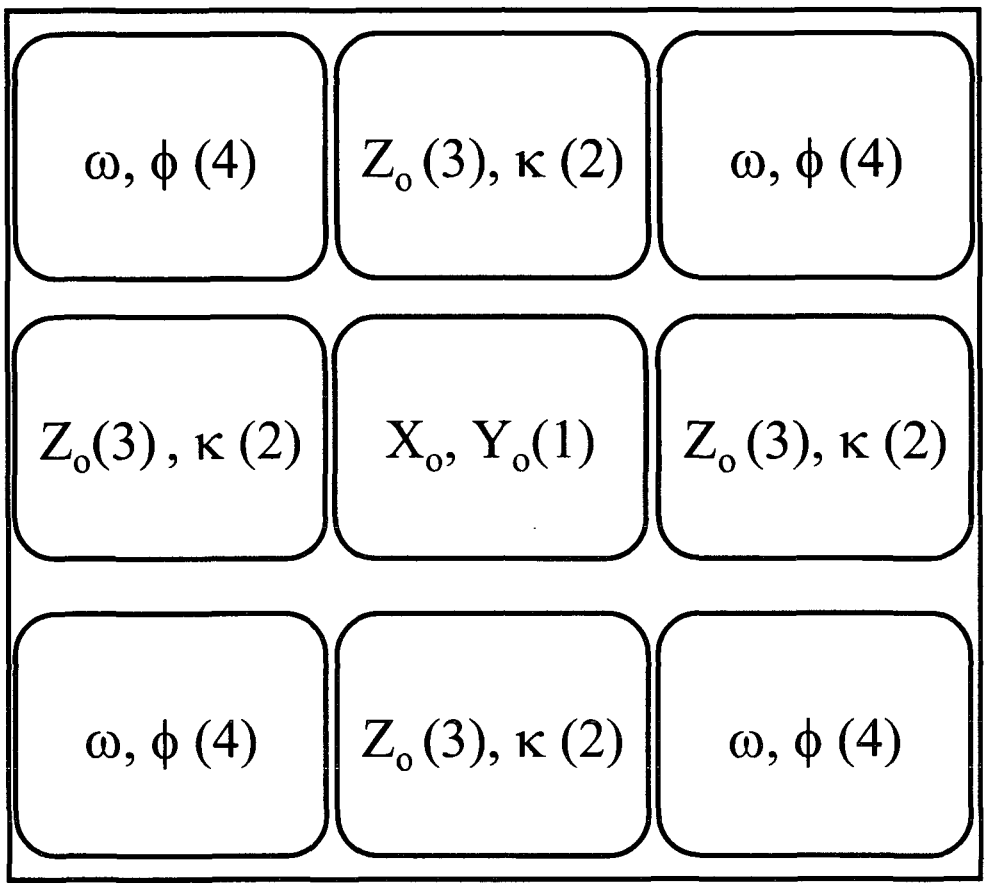


Image Space Linear Features (A)

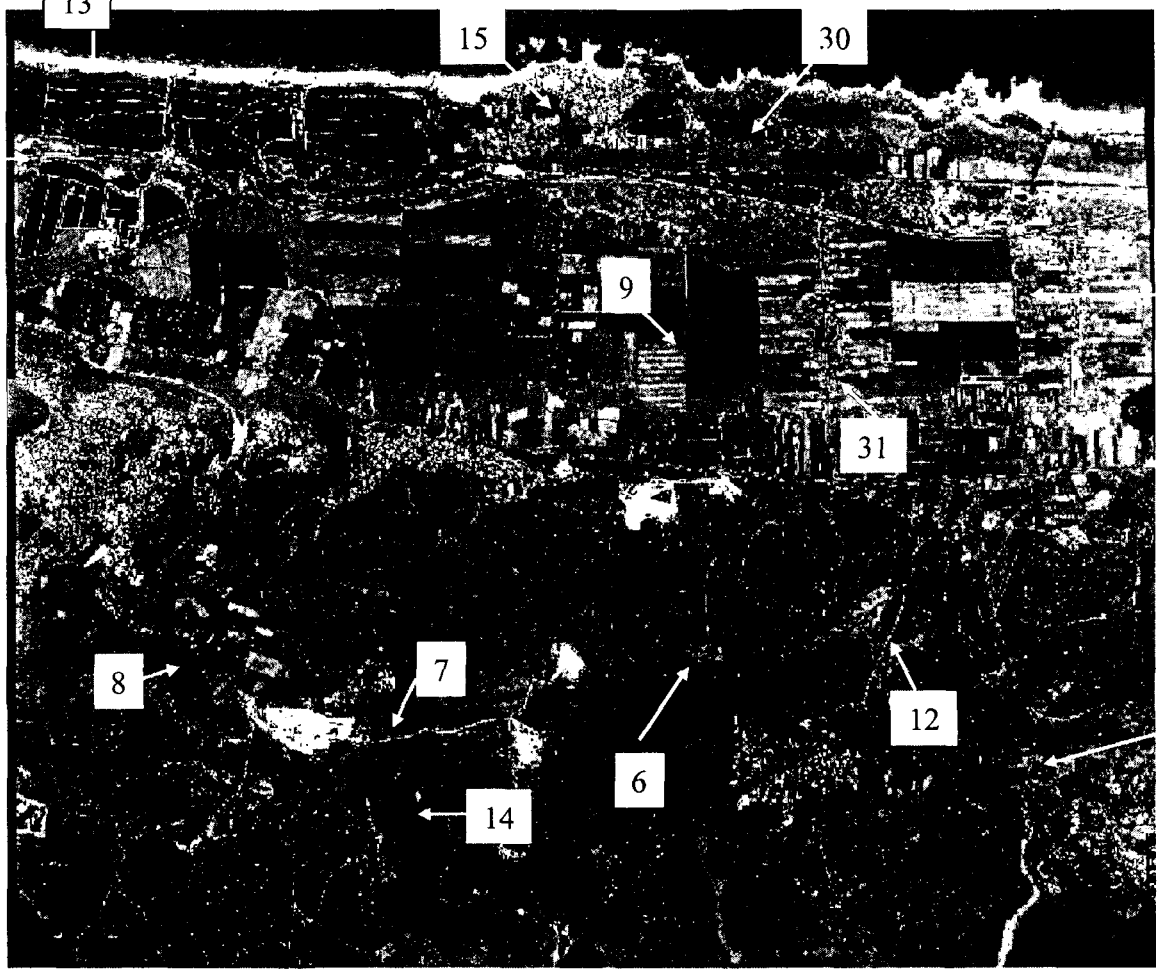
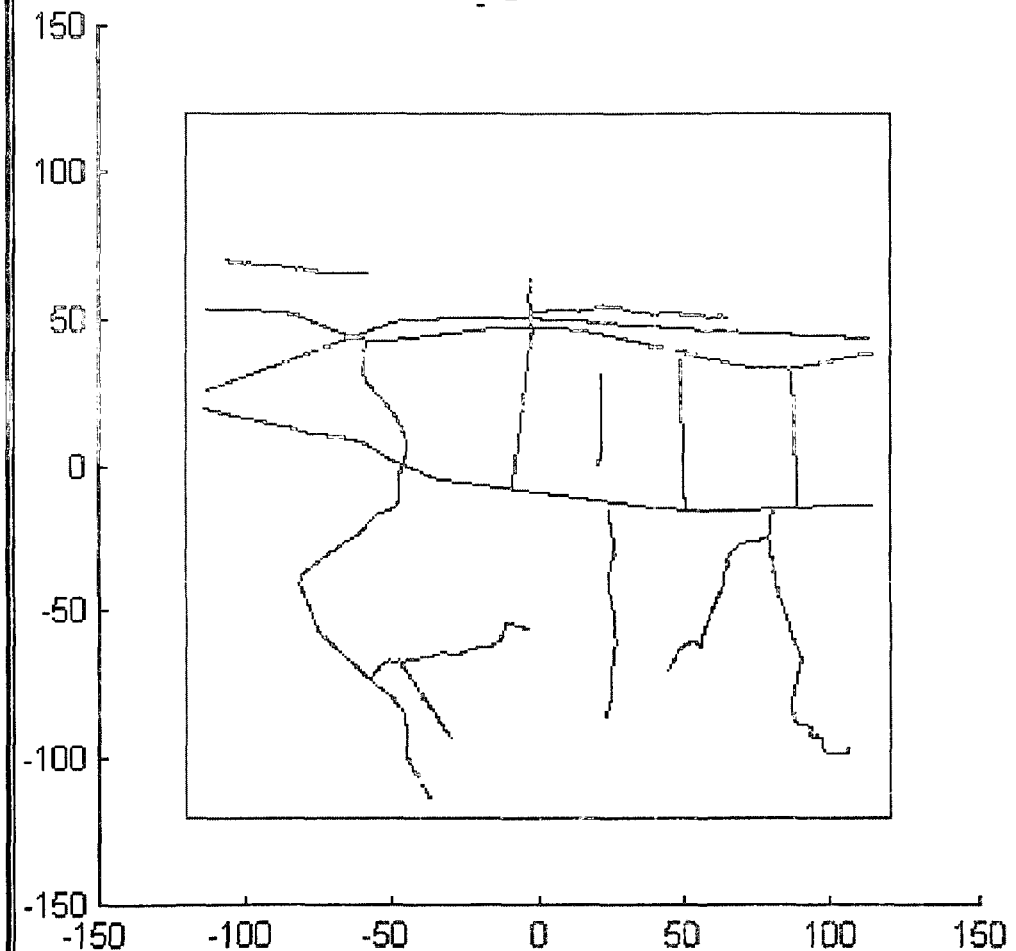


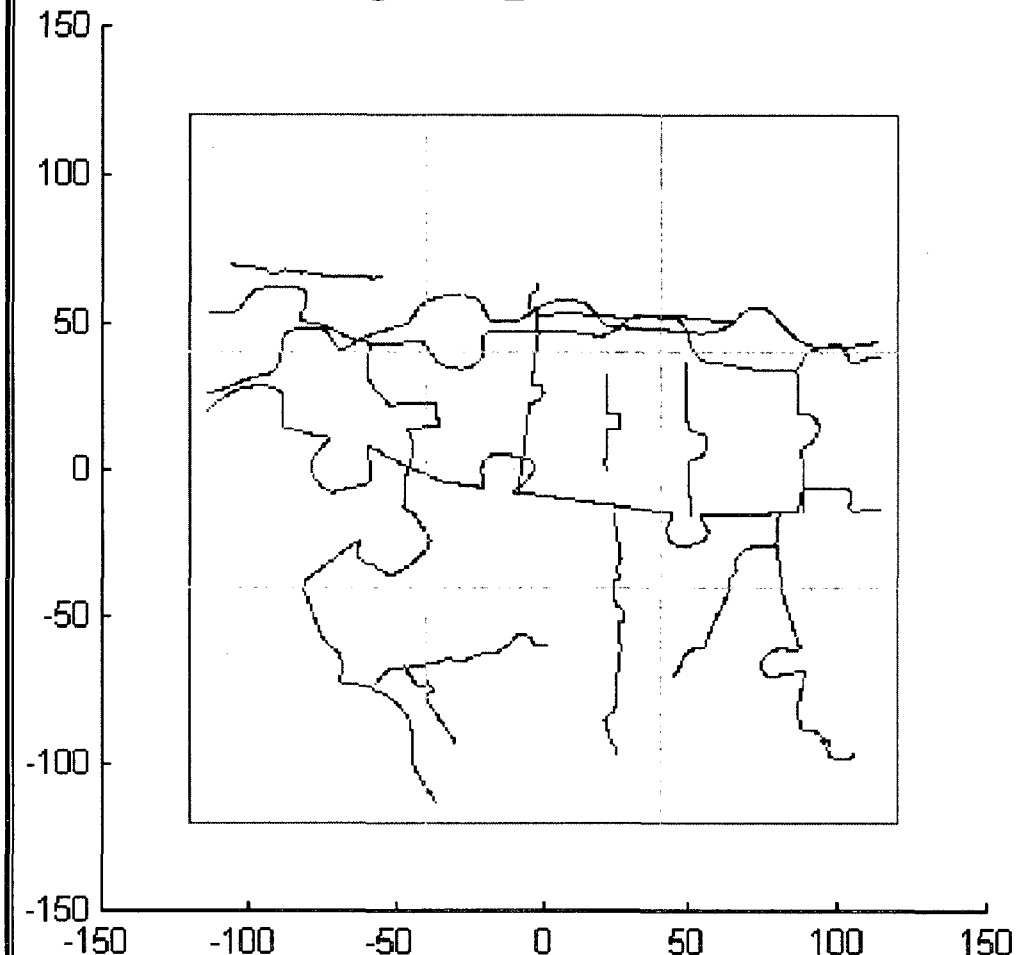
Image Space Linear Features (B)

Image Space Linear Features (A)



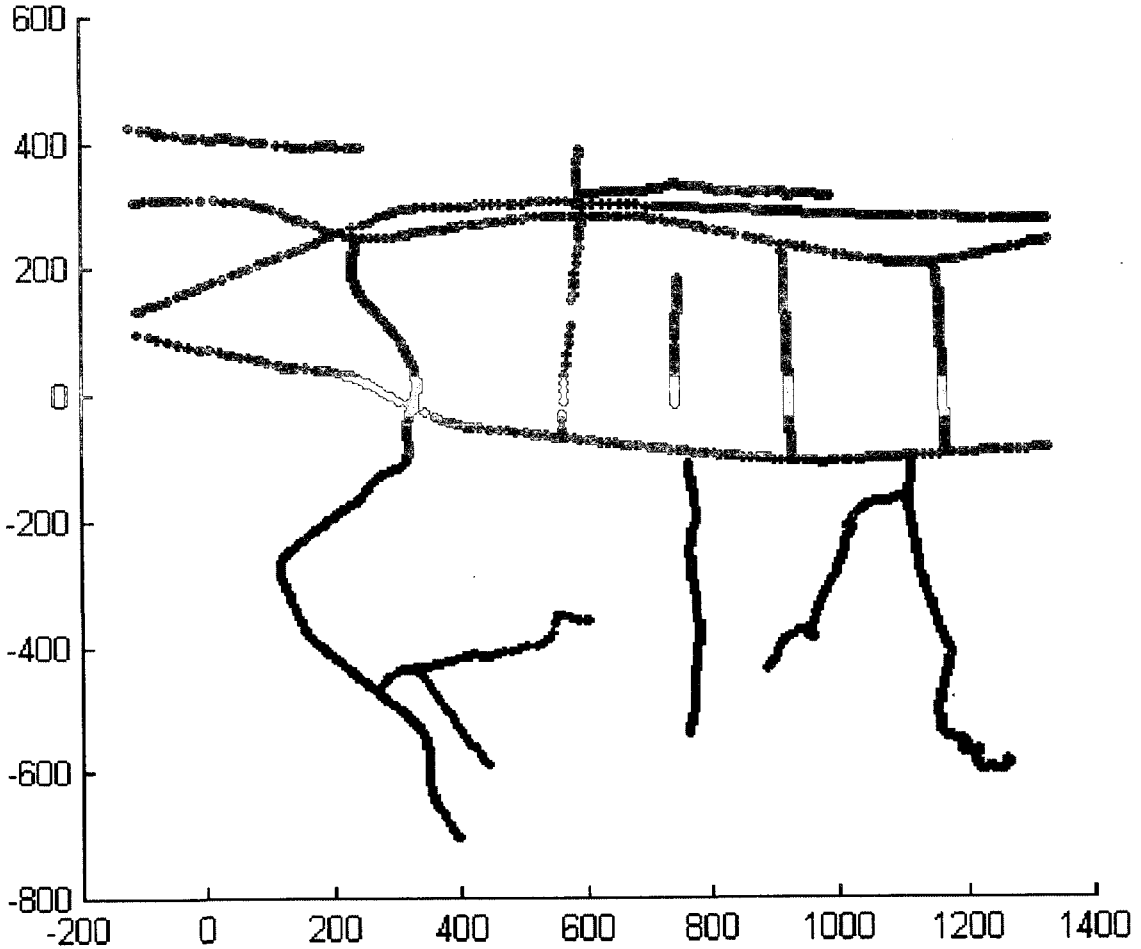
No Digitization Errors
55,178 Points
15 Roads

Image Space Linear Features (B)



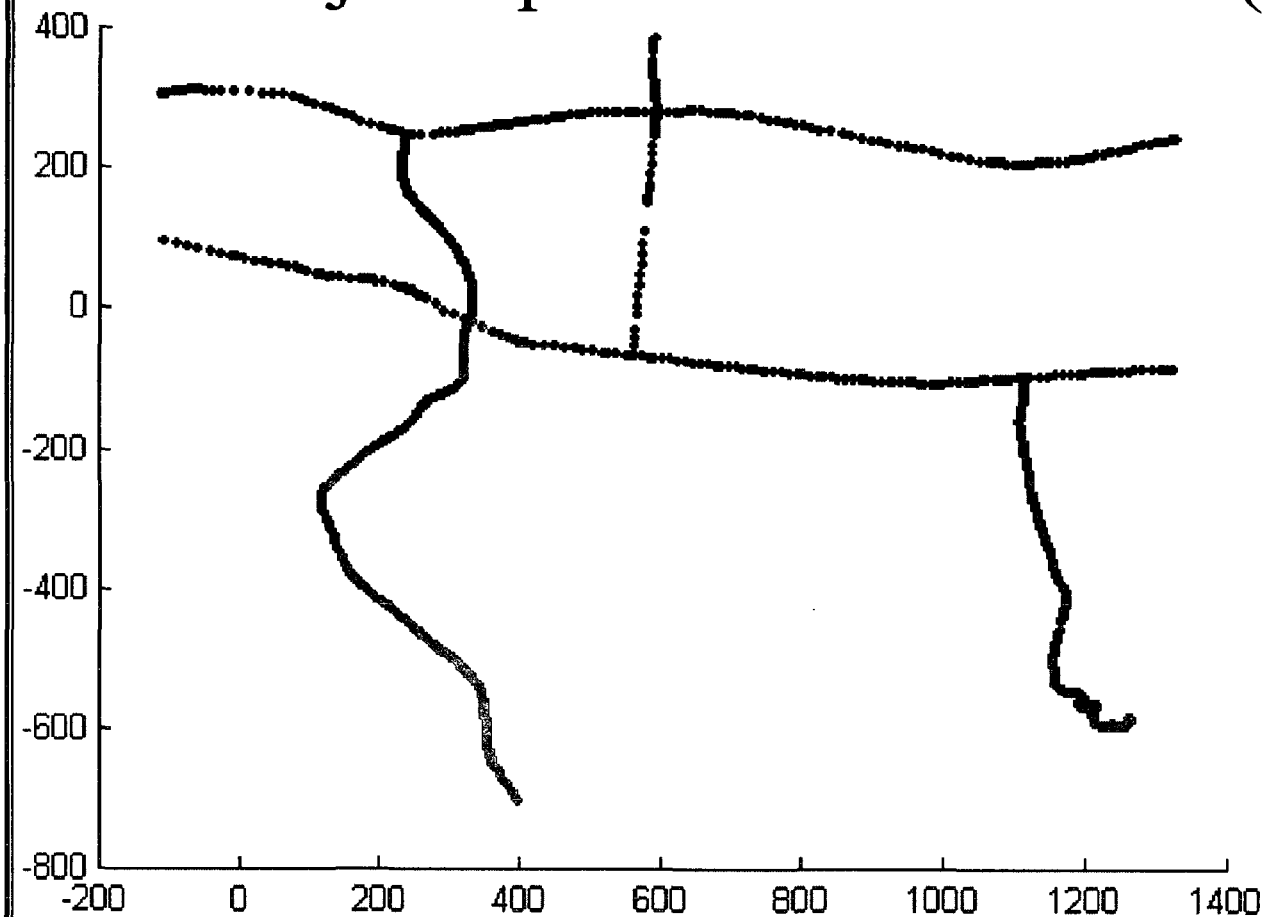
Digitization Errors
63,397 Points
15 Roads

Object Space Linear Features (1)



1572 Points
15 Roads

Object Space Linear Features (2)



799 Points
5 Roads

Experiments

		Object Space		Image Space	
		# of Roads	# of Points	#of Roads	# of Points
No Digitization Errors (A)	**Exp. 1 (1)**	**15**	**1572**	**15**	**55,178**
	Exp. 2 (2)	**5**	**799**	**15**	**55,178**
Digitization Errors (B)	**Exp. 3 (1)**	**15**	**1572**	**15**	**63,397**
	Exp. 4 (2)	**5**	**799**	**15**	**63,397**

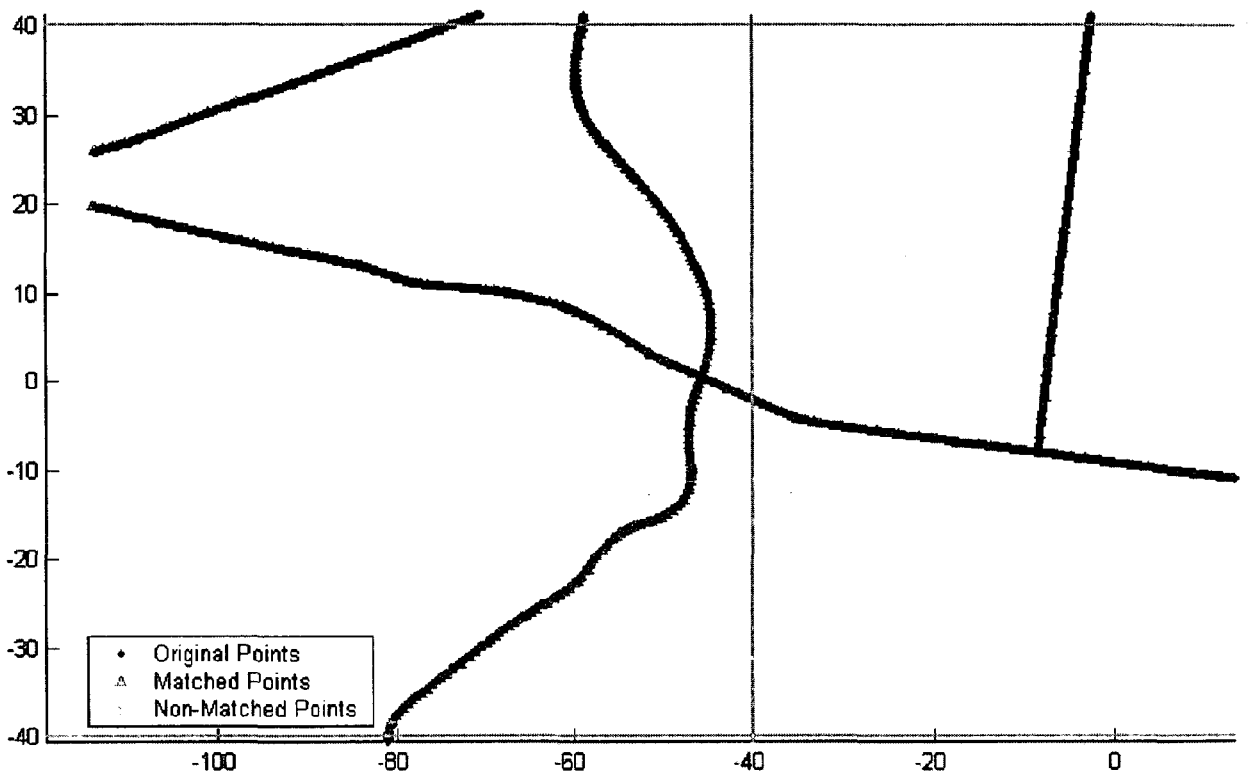
Estimated EOP

	X_o (m)	Y_o (m)	Z_o (m)	$\omega°$	$\phi°$	$\kappa°$
AT (Manual)	**600.00**	**-26.781**	**1014.894**	**0.584667**	**-0.86730**	**1.191474**
Appx.	**450.0**	**100.0**	**900.0**	**9.0**	**-9.0**	**10.0**
Exp. 1	**599.762**	**-26.937**	**1014.842**	**0.590318**	**-0.87206**	**1.185914**
Exp. 2	**599.797**	**-26.663**	**1014.699**	**0.572123**	**-0.87200**	**1.182790**
Exp. 3	**599.722**	**-26.974**	**1014.818**	**0.589120**	**-0.87011**	**1.189792**
Exp. 4	**599.245**	**-27.081**	**1014.754**	**0.594399**	**-0.89559**	**1.183058**

Matching Results

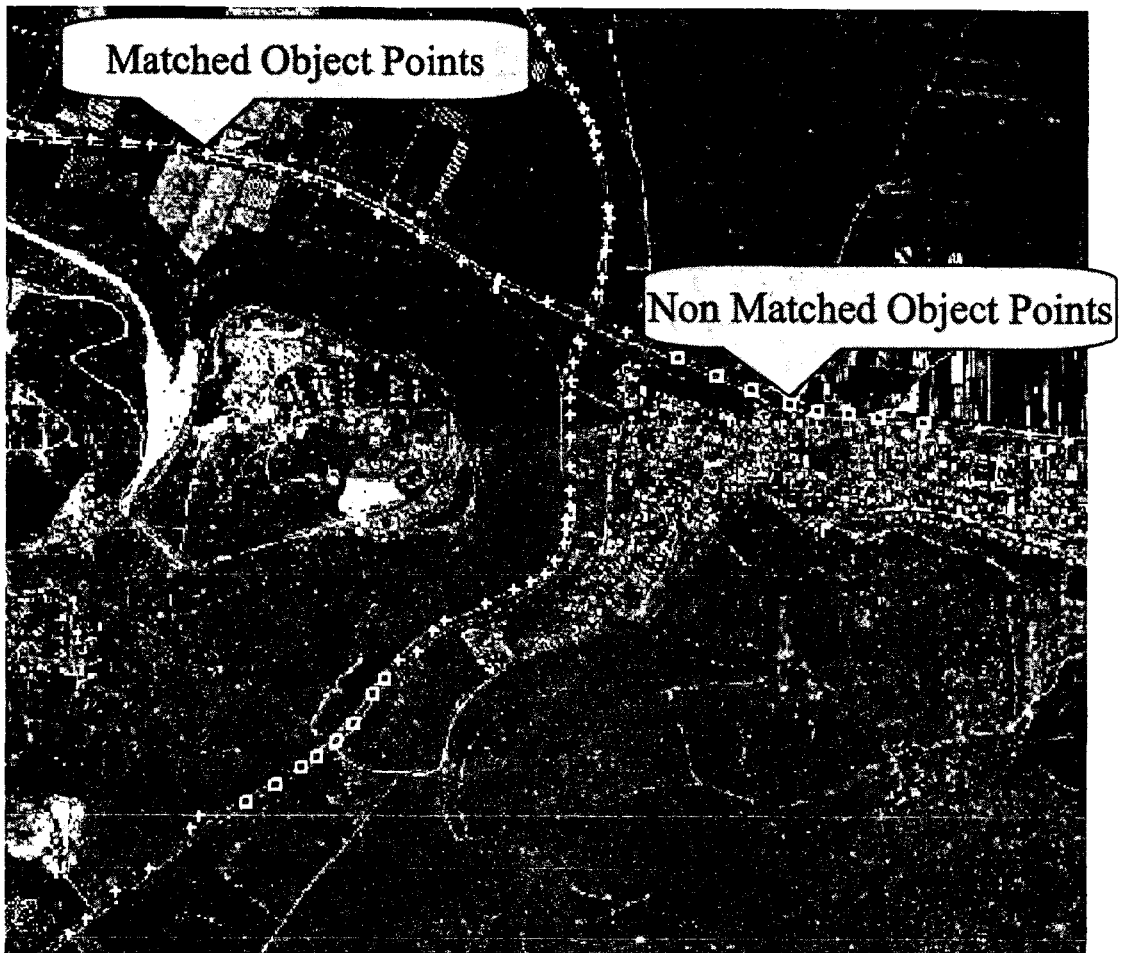
	# of Image Points	# of Object Points	# of Matched Points
Exp. 1	**55,178**	**1572**	**1543 (98%)**
Exp. 2	**55,178**	**799**	**792 (99%)**
Exp. 3	**63,397**	**1572**	**1024 (65%)**
Exp. 4	**63,397**	**799**	**533 (67%)**

Matching Results (No Digitization Errors)

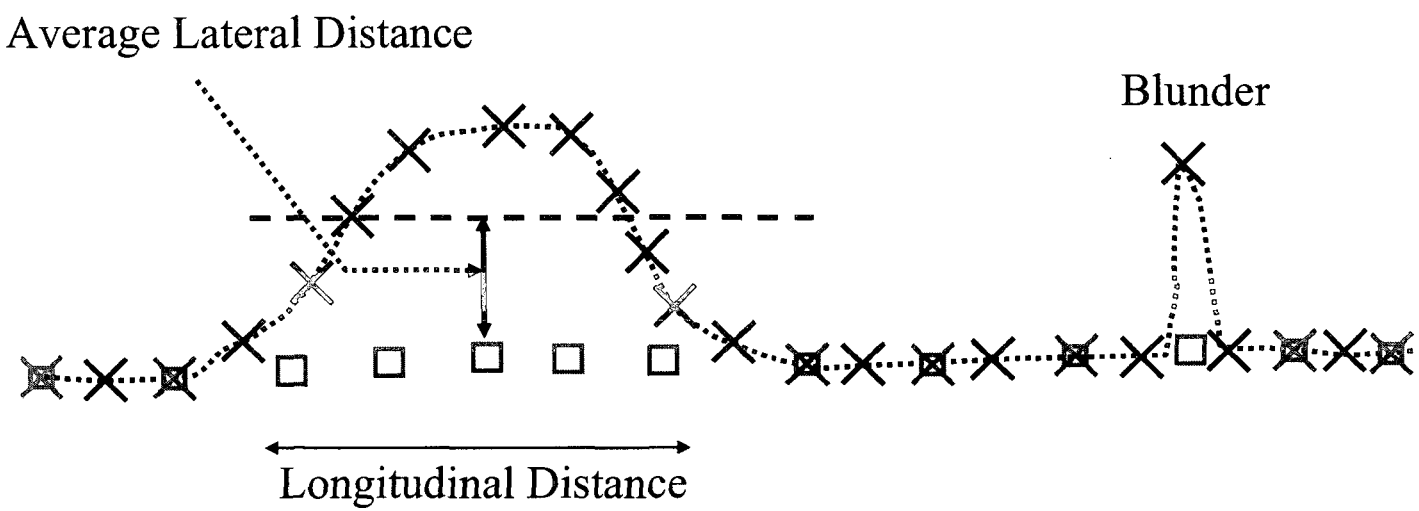


Matching Results (Digitization Errors)

Change Detection

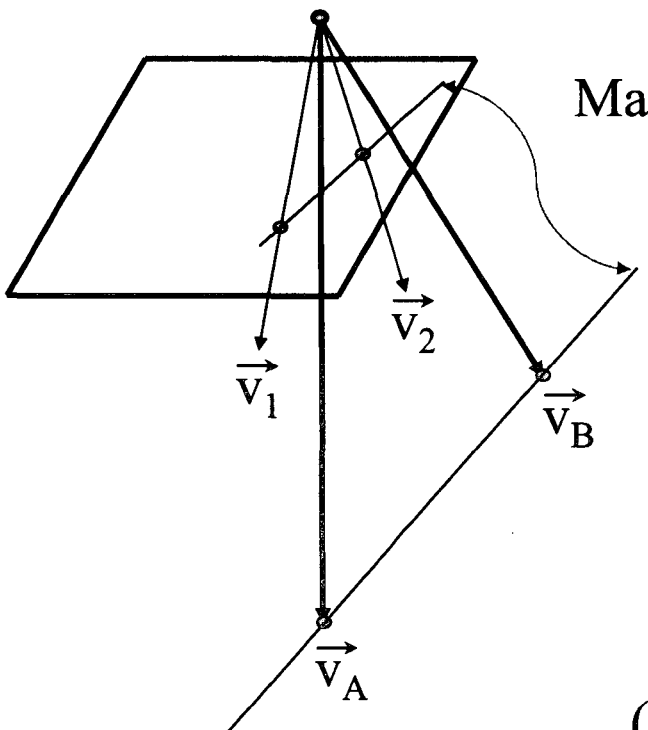


Change Detection



- Digitized points along the image space features.
- Matched object space points after projection to the image space.
- Non matched object space points after projection to the image space.

Single Photo Resection / Line Model

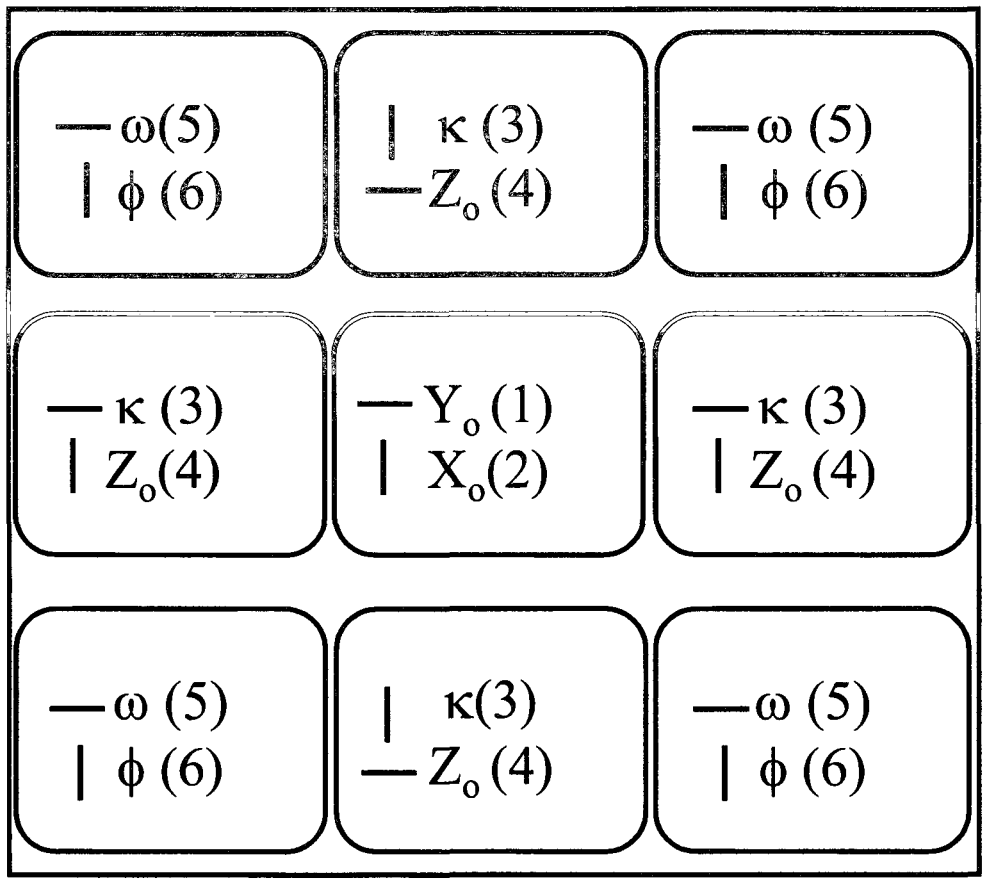


Matching Hypothesis

$$(\vec{V}_A \times \vec{V}_B) \bullet \vec{V}_1 = 0$$

$$(\vec{V}_A \times \vec{V}_B) \bullet \vec{V}_2 = 0$$

Sequential Parameter Estimation



Experiment 1

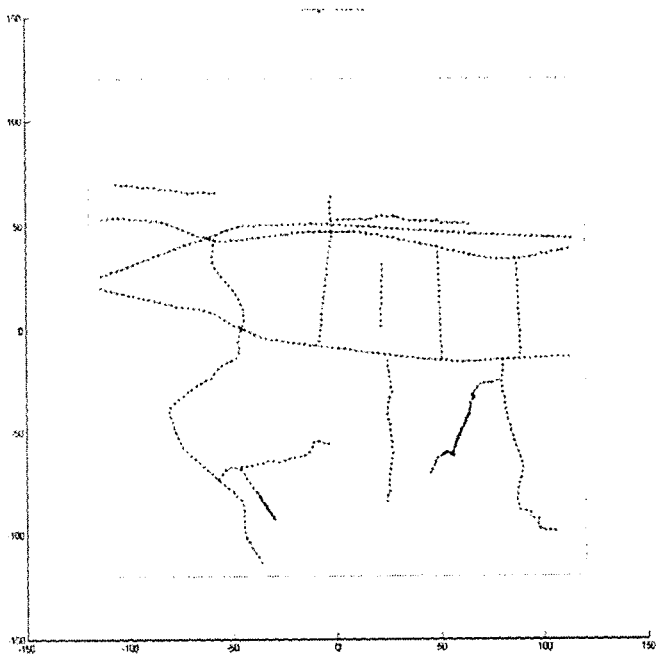
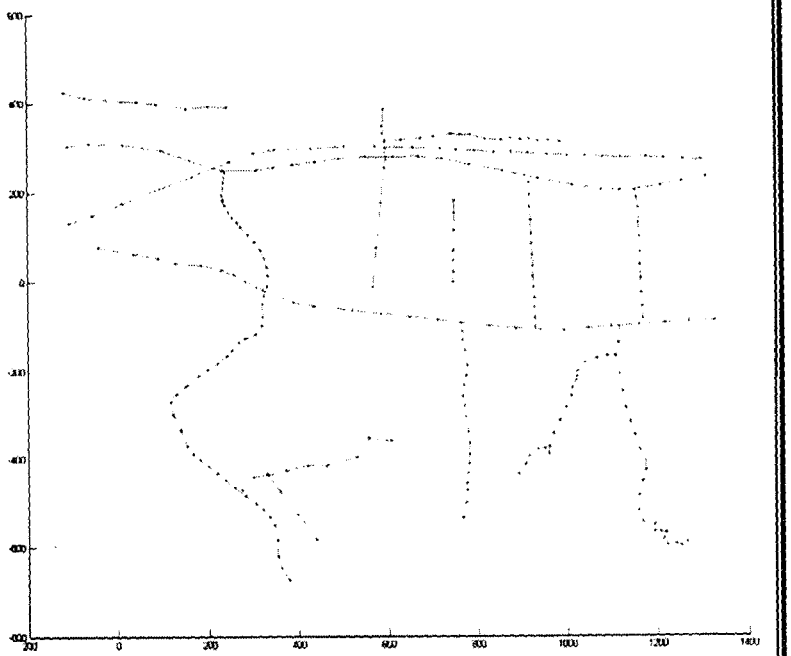


Image Space Features
602 Line Segments



Object Space Features
252 Line Segments

Experiment 1

	X_o (m)	Y_o (m)	Z_o (m)	$\omega°$	$\phi°$	$\kappa°$
Manual	**600.00**	**-26.781**	**1014.894**	**0.584667**	**-0.86730**	**1.191474**
Points	**599.762**	**-26.937**	**1014.842**	**0.590318**	**-0.87206**	**1.185914**
Line Segments	**599.848**	**-26.501**	**1014.807**	**0.565717**	**-0.867154**	**1.188528**

	Points	**Line Segments**
Execution Time	**Hours**	**89 seconds**

Experiment 2

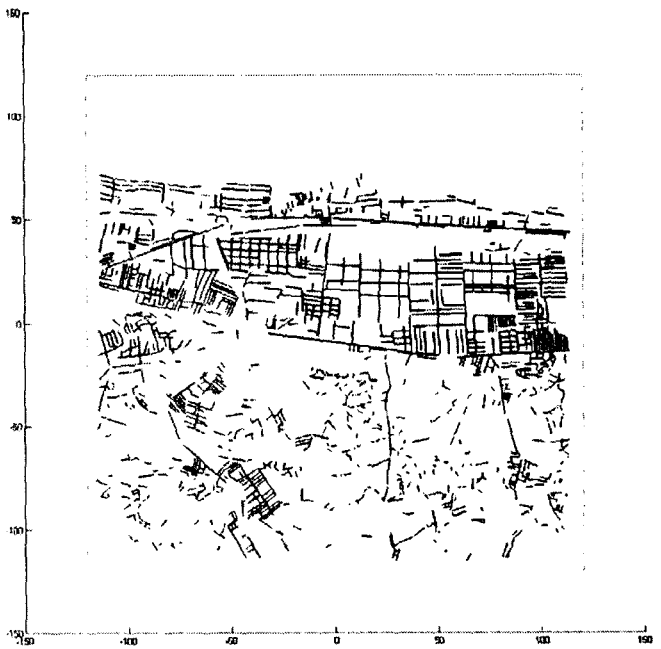
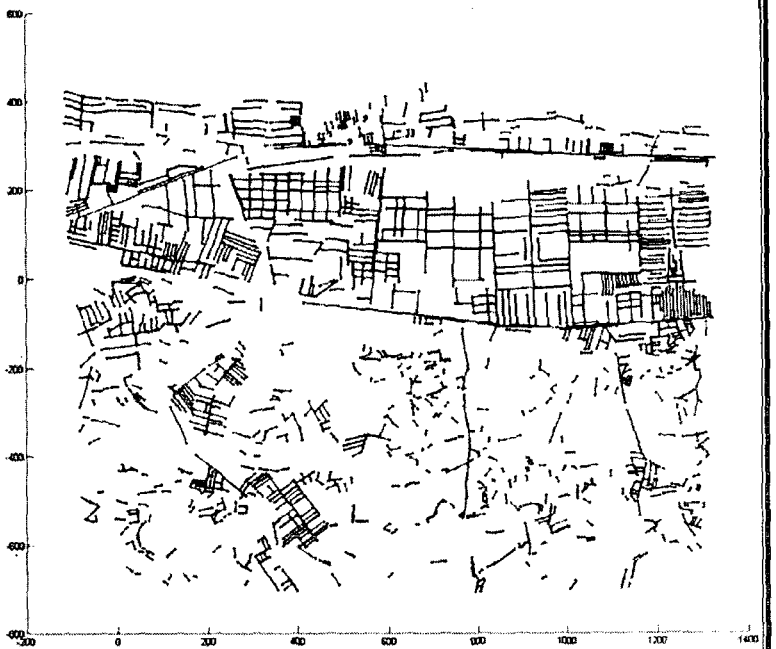


Image Space Features
1331 Line Segments



Object Space Features
1299 Line Segments

Experiment 2

Matching Results

	X_o (m)	Y_o (m)	Z_o (m)	ω°	ϕ°	κ°
AT (Manual)	**600.000**	**-26.781**	**1014.894**	**0.584667**	**-0.86730**	**1.191474**
Appx.	**400.0**	**200.0**	**800.0**	**12.0**	**-12.0**	**14.0**
Exp. 2	**600.161**	**-26.802**	**1014.913**	**0.588591**	**-0.859522**	**1.192321**

Experiment 3

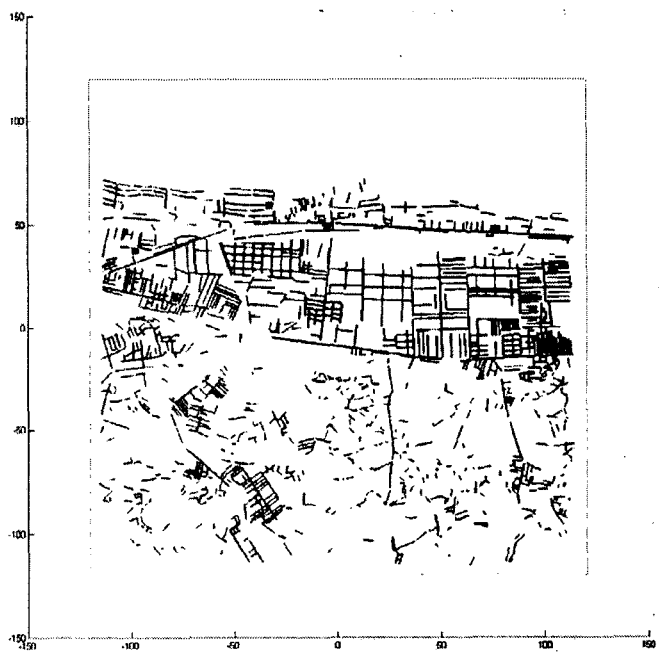
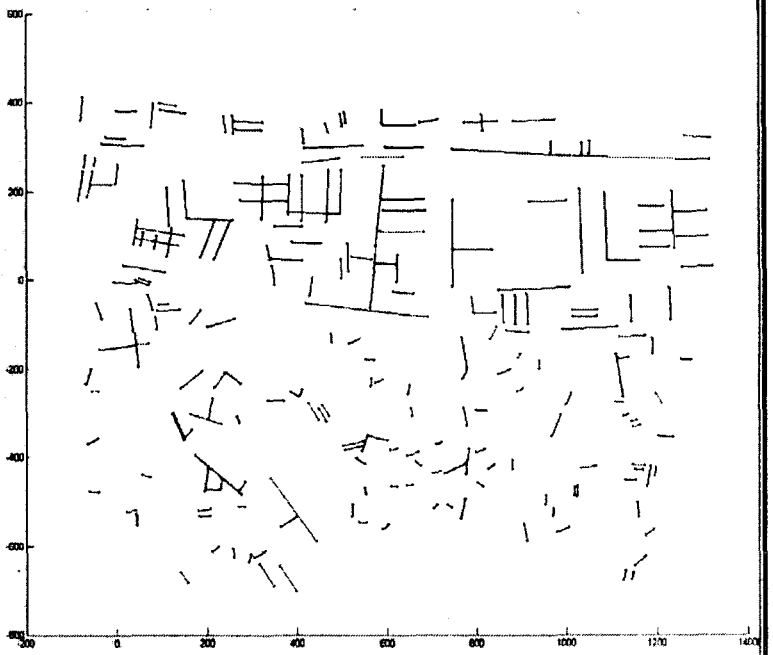


Image Space Features
1331 Line Segments



Object Space Features
224 Line Segments

Experiment 3

Matching Results

	X_o (m)	Y_o (m)	Z_o (m)	ω°	ϕ°	κ°
AT (Manual)	**600.000**	**-26.781**	**1014.894**	**0.584667**	**-0.86730**	**1.191474**
Appx.	**510.0**	**90.0**	**910.0**	**4.0**	**-4.0**	**4.0**
Exp. 3	**600.130**	**-26.753**	**1015.044**	**0.582727**	**-0.865468**	**1.187548**

Conclusion

- The conducted experiments proved the feasibility of the suggested algorithm for automatically solving the co-registration problem.
- This approach solves for the parameters and the correspondence simultaneously.
- The proposed technique is useful for:
  - Working with control linear features.
  - Surface matching and reconstruction.
  - Change detection.
- This is a robust parameter estimation technique.
  - Blunders (discrepancies) are filtered out.

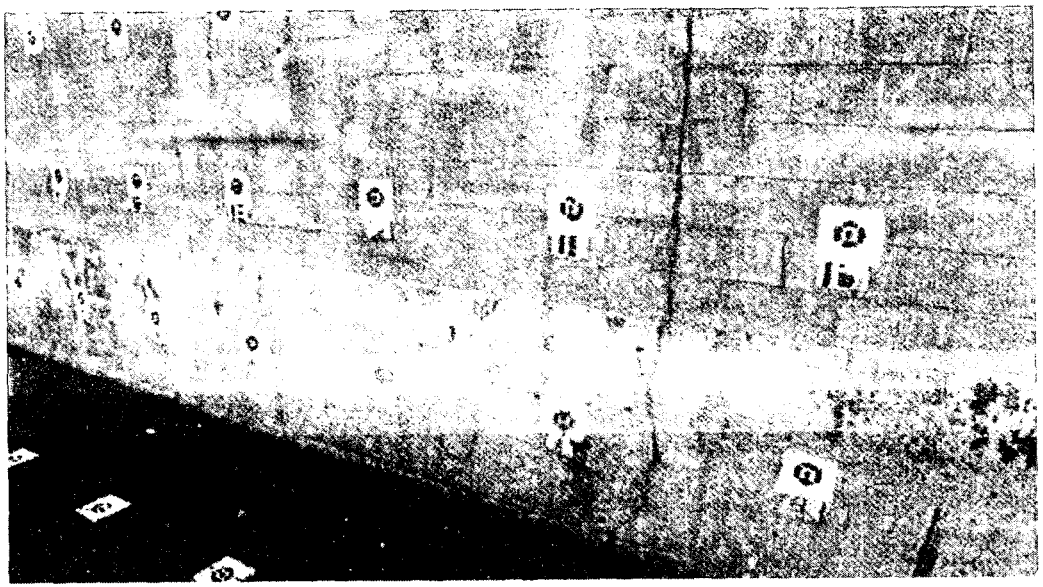
Future Work

- Improve the efficiency of the algorithm:
  - Accumulator array.
  - Optimum sequence for parameter estimation.
  - Noise consideration.
- Improve change detection capabilities.
- Performing ARO and surface reconstruction in a hierarchical fashion.
  - Analyze the reconstructed surface for:
    - Densification/Interpolation boundaries.
    - Object recognition purposes.
- Look for more applications.

Other Research Activities

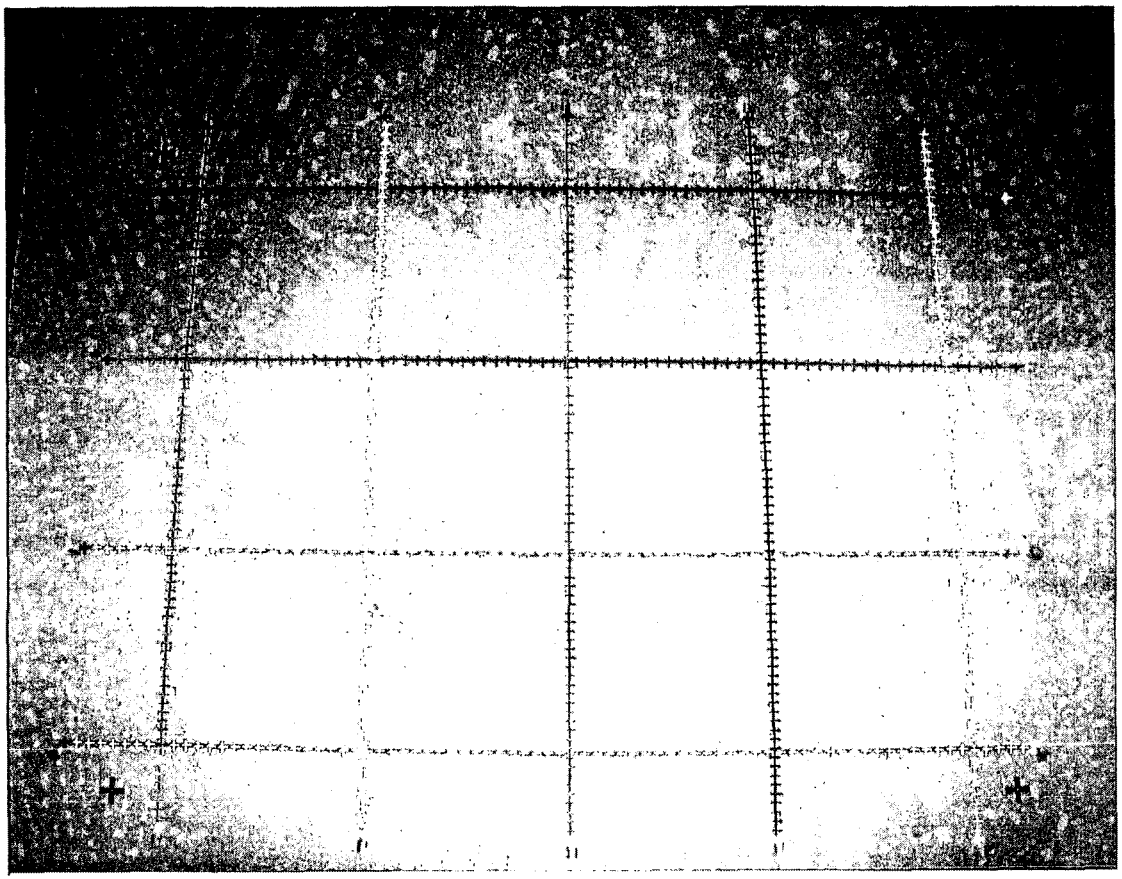
- Modeling line cameras:
  - Rigorous modeling using a camera model.
    - Pose estimation using control linear features.
  - Affine transformation (no need for camera model).
- Close-range photogrammetric applications using off-the-shelf digital cameras:
  - Alternative approach for camera calibration.
    - Very simple test field (a group of straight lines).
    - Automated calibration.
  - Developing a complete system for precise three-dimensional measurements from imagery.

Traditional Test Field

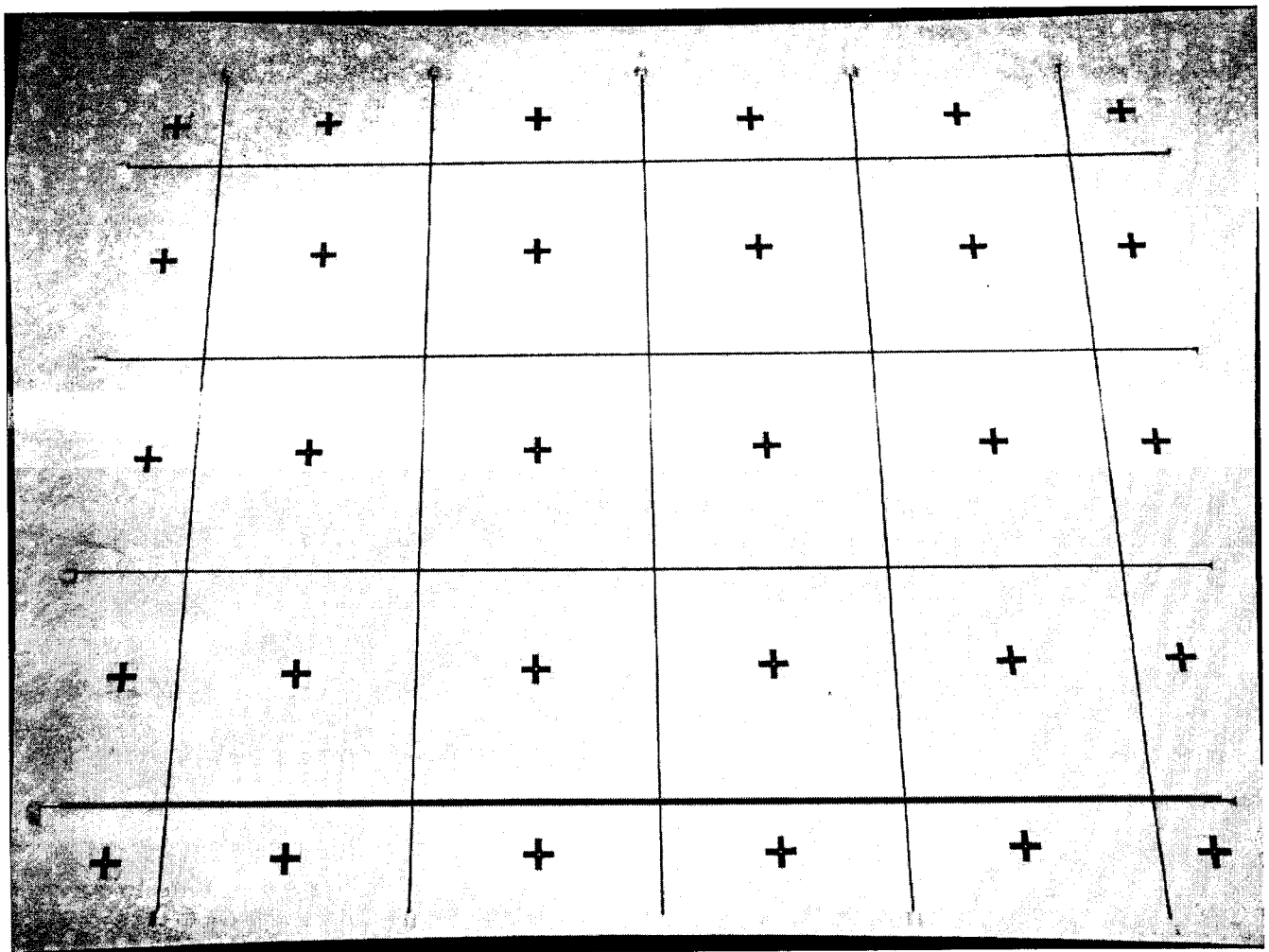


Theodolite Intersection

Calibration Images



Before / After Calibration



Calibration Results

	Point Based	Line Based
x_p (mm)	**-0.1247 (±0.0040)**	**-0.1224 (±0.0016)**
y_p (mm)	**-0.0707 (±0.0042)**	**-0.0642 (±0.0015)**
c (mm)	**11.6041 (±0.0118)**	**11.6034 (±0.0048)**
K_1	**-1.118769e-03**	**-1.174221e-03**

- Reconstructed object spaces using the different IOP have been compared through root mean square error analysis.

Number of Points	**30**
RMS_X (m)	**0.00047**
RMS_Y (m)	**0.00047**
RMS_Z (m)	**0.00040**