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Metric Exploitation of a Single Low Oblique Aerial Image

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Introduction

- 1839: First oblique aerial image (Daguerre)
- Subsequent years: oblique aerial images for mapping and reconnaissance purposes
- Recent years: Oblique aerial images → a complementary dataset to traditional vertical airborne images

the basic source of information for various kinds of applications

- 3D modeling
- Digital monoplotting
- Scene interpretation and classification for cadastral, military and infrastructural projects

Aerial platforms equipped with multiple cameras (both oblique and vertical images)

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Metric exploitation of oblique aerial images

→ Goal of several companies and organizations

issue of major significance for many applications

- 3D cadastre projects
- Urban planning
- Real estate
- Property management
- Cultural heritage documentation
- …

Provision of software

using

- the camera exterior orientation information
- ground elevation data

FIG
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Purpose of our work

- Presentation of a workflow for
  making **measurements of** → vertical distances / horizontal distances
  from a single low oblique aerial image
  without knowledge of the camera six-degrees-of-freedom pose
- The investigation of the **accuracy** that can be achieved

high oblique image → tilted sufficiently to show the horizon
low oblique image → they do not include the horizon

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Input data

- a **low oblique** aerial image
- the camera **interior orientation**
- the **flying height** of the aerial platform
- *For vertical distances*: the **difference in elevation** between the ground nadir and the point at the bottom of the vertical object
- *For horizontal distances*: the **difference in elevation** between the ground nadir and the endpoints of the horizontal line segment to be measured

average elevation difference between the region under the aerial platform and the region of interest depicted in the oblique photograph
e.g., from Google Earth

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Workflow

Automatic nadir point detection

- Undistortion of the image
- Automatic detection of the true horizon line
- Initial estimation of the nadir point
- Final estimation of the nadir point

Calculation of vertical and horizontal distances

Mathematical model used for the calculation of vertical distances

Mathematical model used for the calculation of horizontal distances

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Undistortion of the image

❖ Correction of the lens distortion effect over the oblique image, using the calibration output of the airborne camera

- the pixel coordinates of the principal point
- the camera constant
- the coefficients of radial (and tangential) lens distortion polynomials

according to the Brown-Conrady model

Undistorted image

automatic detection of the nadir point

photogrammetric measurements of distances

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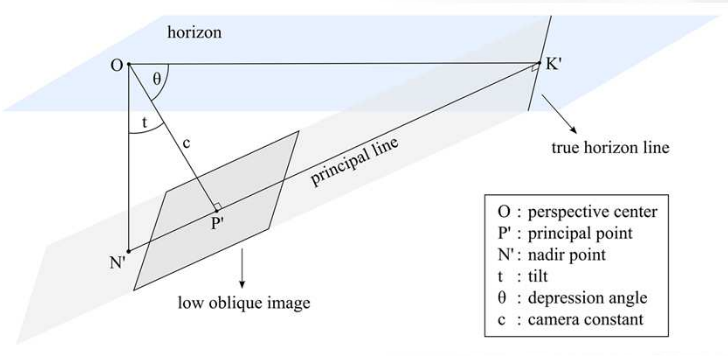
Automatic detection of the true horizon line (1/2)



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Automatic detection of the true horizon line (2/2)

- Detection of edges using the Canny edge detector
- Extraction of line segments using the Progressive Probabilistic Hough Transform
- Detection of the vanishing points of two horizontal directions
- Computation of the true horizon line

1. Estimation of the intersection point of most horizontal line segments
2. Generalized least-squares adjustment for the calculation of the vanishing point
3. Removal of horizontal line segments that converge to the first detected vanishing point
4. Steps 1 and 2 are repeated, for the detection of a second horizontal vanishing point

Variation of the RANSAC algorithm

the initial estimation of the intersection point lies outside the image limits

FIG
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Initial estimation of the nadir point

- Determination of the principal line ➡
  - perpendicular to the true horizon line
  - passes through the principal point
- Geometric calculation of the distance P´N´ between the principal point and the nadir point
- Determination of the coordinates of the nadir point
  - using the distance P´N´ and the coordinates of the principal point and
  - taking into consideration the fact that the nadir point lies on the principal line

two solutions → only the solution according to which the nadir point is located below the principal point is correct

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Final estimation of the nadir point

Detection of edges using the Canny edge detector — different thresholds → more edges are detected → vertical edges are also extracted in addition to horizontal ones

↓

Extraction of line segments using the Progressive Probabilistic Hough Transform

↓

Rejection of non vertical line segments — using the initial estimation of the nadir point

↓

Calculation of the coordinates of the nadir point using a variation of the RANSAC algorithm — the random iterative choice of two line segments is controlled, so that their intersection point lies close to the initial estimation of the nadir point

↓

Final estimation of the nadir point through least-squares adjustment

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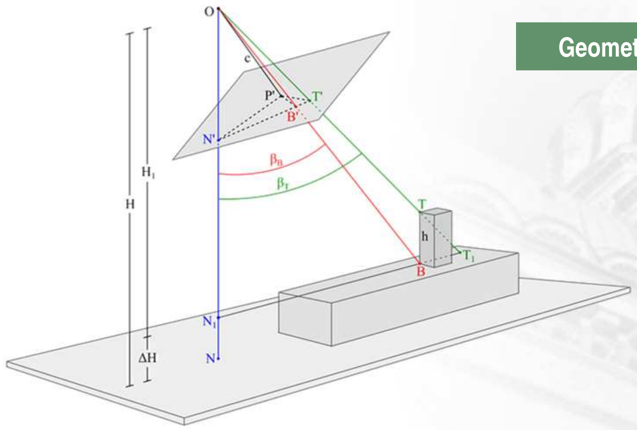
Calculation of vertical distances



Geometrically proved

- Similar triangles
- Law of cosines
- Trigonometric identities
- Pythagorean Theorem

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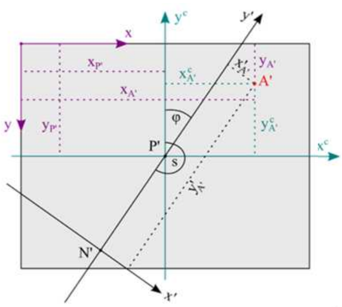
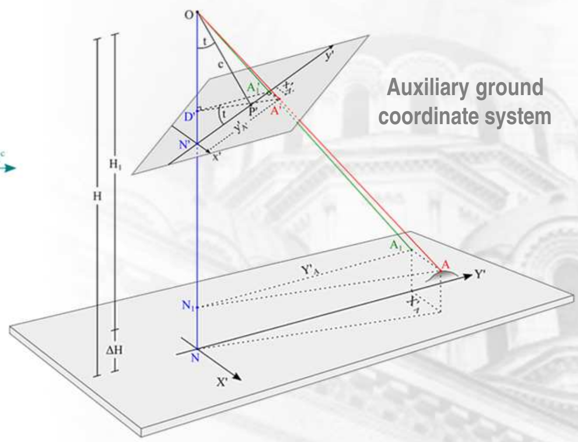
Calculation of horizontal distances



Auxiliary image coordinate system



Auxiliary ground coordinate system

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Assessment of errors (1/4)

The variables that may affect the accuracy of the measurement of a vertical or a horizontal distance, due to their values and errors, are the following:

- the flying height
- the elevation difference ΔH
- the relative image positions of the two points being measured, which determine the length of their distance
- the camera interior orientation parameters
- the position of the nadir point in the image, which depends on the tilt of the camera axis and the camera constant

FIG
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Assessment of errors (2/4)

Assuming that:

- the camera interior orientation is known with very high accuracy (zero errors)
- the measurements of the image points are very accurate (error of 0.5 pixel in the measured coordinates of each point)
- the nadir point is accurately determined (error of 10 pixels in x and y coordinates)

and considering

- a camera resolution of 60 MP and
- a pixel size of 6 μm

the standard errors of the measured vertical and horizontal distances were calculated by error propagation for 4 case studies and for different combinations of the camera constant, the tilt angle and the flying height.

FIG
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Assessment of errors (3/4)

Standard errors of vertical distances (m)								
σ_H=0.5 m								
h (m): 3 – 40	$\sigma_{\Delta H}$=0.15 m				$\sigma_{\Delta H}$=10 m			
	t=15º		t=35º		t=15º		t=35º	
	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm
H=200 m	0.47-1.10	0.03-0.12	0.05-0.12	0.01-0.11	0.49-2.28	0.15-2.00	0.16-2.00	0.15-2.00
H=500 m	1.16-1.58	0.08-0.11	0.11-0.13	0.03-0.05	1.16-1.77	0.10-0.81	0.13-0.81	0.07-0.80
H=1000 m	2.31-2.52	0.15-0.17	0.23-0.23	0.06-0.07	2.32-2.55	0.16-0.43	0.23-0.46	0.07-0.41
σ_H=15 m								
h (m): 3 – 40	$\sigma_{\Delta H}$=0.15 m				$\sigma_{\Delta H}$=10 m			
	t=15º		t=35º		t=15º		t=35º	
	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm
H=200 m	0.52-3.19	0.23-3.00	0.23-3.00	0.23-3.00	0.54-3.77	0.27-3.61	0.27-3.61	0.27-3.61
H=500 m	1.17-1.98	0.12-1.20	0.15-1.21	0.10-1.20	1.17-2.14	0.13-1.45	0.16-1.45	0.11-1.44
H=1000 m	2.32-2.59	0.16-0.62	0.24-0.64	0.08-0.60	2.33-2.62	0.16-0.74	0.24-0.76	0.08-0.72

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Assessment of errors (4/4)

Standard errors of horizontal distances (m)								
σ_H=0.5 m								
d (m): 10 – 90	$\sigma_{\Delta H}$=0.15 m				$\sigma_{\Delta H}$=10 m			
	t=15º		t=35º		t=15º		t=35º	
	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm
H=200 m	0.03-0.24	0.03-0.24	0.03-0.24	0.03-0.24	0.50-4.51	0.50-4.51	0.50-4.51	0.50-4.51
H=500 m	0.04-0.13	0.02-0.10	0.04-0.11	0.02-0.10	0.20-1.80	0.20-1.80	0.20-1.80	0.20-1.80
H=1000 m	0.07-0.12	0.03-0.06	0.07-0.10	0.03-0.06	0.12-0.91	0.10-0.90	0.12-0.91	0.11-0.90
σ_H=15 m								
d (m): 10 – 90	$\sigma_{\Delta H}$=0.15 m				$\sigma_{\Delta H}$=10 m			
	t=15º		t=35º		t=15º		t=35º	
	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm	c=50 mm	c=150 mm
H=200 m	0.75-6.75	0.75-6.75	0.75-6.75	0.75-6.75	0.90-8.11	0.90-8.11	0.90-8.11	0.90-8.11
H=500 m	0.30-2.70	0.30-2.70	0.30-2.70	0.30-2.70	0.36-3.25	0.36-3.25	0.36-3.25	0.36-3.25
H=1000 m	0.17-1.36	0.15-1.35	0.17-1.35	0.15-1.35	0.19-1.63	0.18-1.62	0.19-1.63	0.18-0.62

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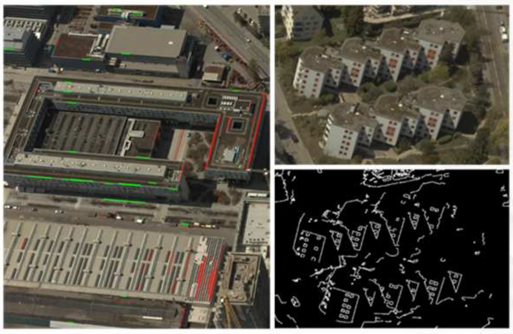
Application development and testing



- C++ programming language
- OpenCV library
- MPIR (Multiple Precision Integers and Rationals) library

Test dataset

- low oblique aerial images
- Leica RCD30 oblique camera system
- H≈520 m
- tilt angle of 35º
- 9000 x 6732 pixels
- pixel size of 6 μm
- c=53 mm

The results were compared to stereoscopic measurements using 3 pairs of georeferenced vertical aerial images

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Conclusions

- An increase in the camera constant and in the tilt of the camera axis leads to higher accuracy in height measurements.
- The standard error of a horizontal distance is almost independent from the camera constant and the tilt angle.
- An increase in the error of H and in the error of ΔH generally increases the error of both vertical and horizontal distances. An increase in the flying height reduces the effect of these errors on the standard error of the distance being measured.
- The standard error of a greater vertical and horizontal distance is generally worse than the error of a shorter one. An increase in the flying height reduces the effect of the length of the line segment on its standard error.

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Future work

- ✓ More extended analysis of the errors of the measured distances
  - by adopting different flight configurations
  - by considering multiple scenarios as far as the availability of ground elevation data is concerned
  - by conducting additional field work for the evaluation of the results
- ✓ Evaluation of the effects of the earth curvature and the atmospheric refraction
- ✓ Metric exploitation of high oblique aerial images

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Thank you for your attention!

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