
ON INS/GNSS-BASED TIME SYNCHRONIZATION IN PHOTOGRAMMETRIC AND REMOTE SENSING MULTI-SENSOR SYSTEMS

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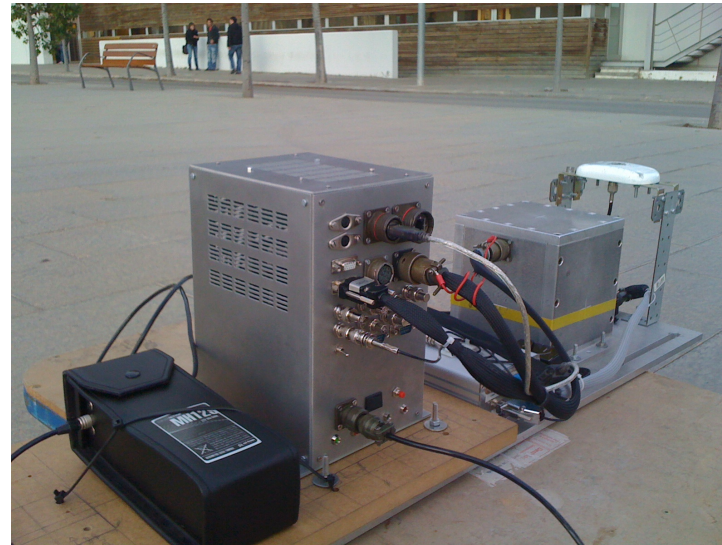
MOTIVATION: MULTI-SENSOR SYSTEMS



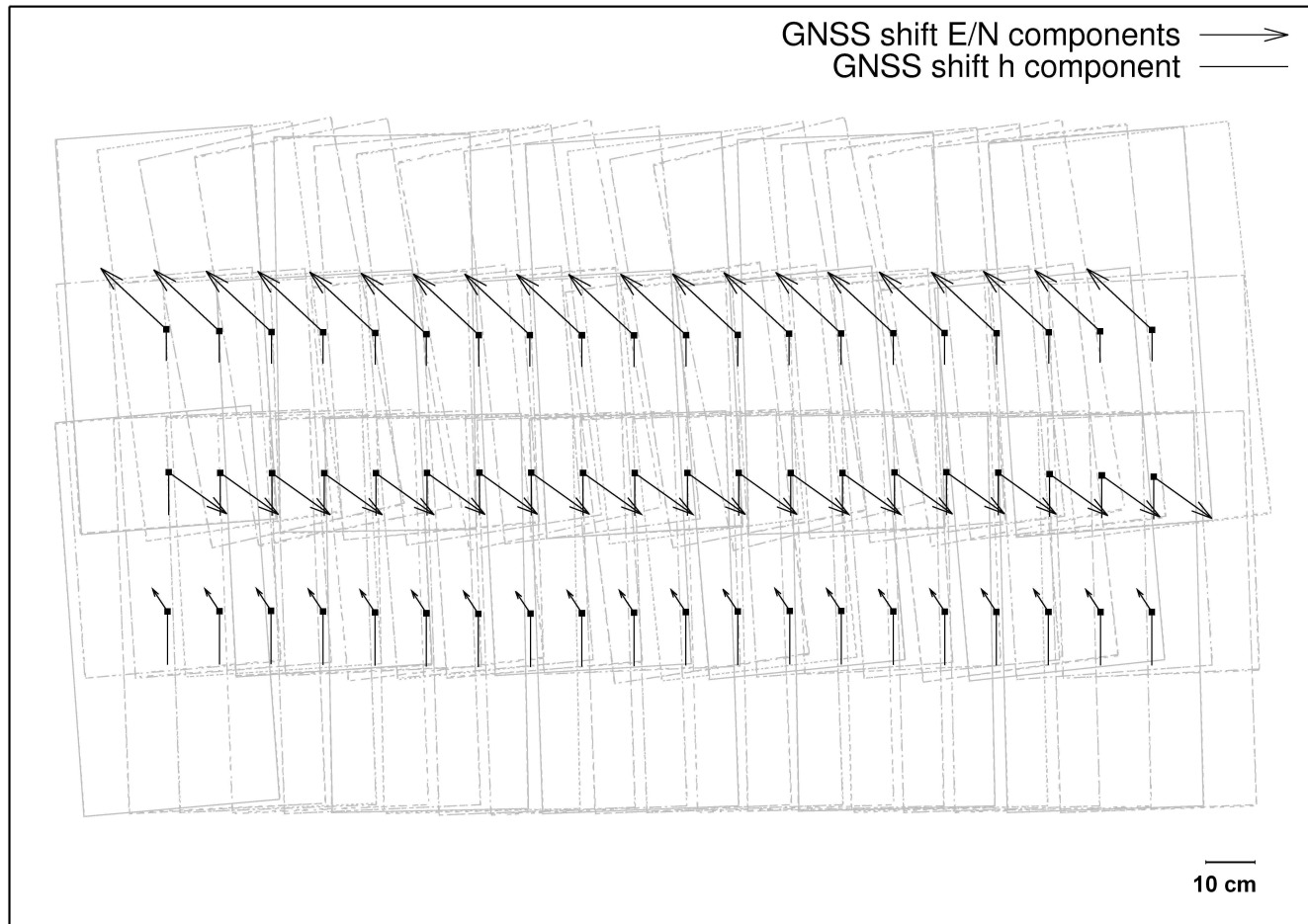
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MOTIVATION: SHIFTS & MORE



AGENDA

- Introduction
- Mathematical functional models
- Space-time network geometry
- Concept validation
- Conclusions

INTRODUCTION

- Multi-sensor systems
- Time synchronization
- 4D problem:
 - Calibration of a constant time synchronization error.
 - Exploitation of tPVA INS/GNSS available data.

	Problem	INS/GNSS	Time calibration
Sensor	3D	–	–
System	3D	tPA	×
	4D	tPVA	✓

THE MODELS

tPA VS tPVA AERIAL CONTROL MODELS IN l CRF

- tPA Position-Attitude Aerial Control in l -frame:

$$X^l + v_X^l = P^l + R_c^l(\Gamma) \cdot (A^c + N^c) + S^l$$

$$R_c^l(\Gamma) = R_b^l(\chi + v_\chi) \cdot R_c^b$$

- tPVA Position-Velocity-Attitude Aerial Control in l -frame:

$$X^l + v_X^l = P^l + R_c^l(\Gamma) \cdot (A^c + N^c) + S^l - (V^l + v_V^l) \cdot \delta t$$

$$R_c^l(\Gamma) = R_b^l(\chi + v_\chi) \cdot R_c^b$$

Blázquez, M., 2008. A new approach to spatio-temporal calibration of multi-sensor systems. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 37 (B1): 481 - 486.

tPA VS tPVA AERIAL CONTROL MODELS IN m CRF

- tPA Position-Attitude Aerial Control in m -frame:

$$X^m + v_X^m = P^m + R_c^m(\Gamma) \cdot (A^c + N^c) + S^m$$

$$R_c^m(\Gamma) = R_l^m(\eta) \cdot R_b^l(\chi + v_\chi) \cdot R_c^b$$

Blázquez, M., Colomina, I., 2012. Relative INS/GNSS aerial control in integrated sensor orientation: models and performance. ISPRS Journal of Photogrammetry and Remote Sensing 67: 120 - 133.

- tPVA Position-Velocity-Attitude Aerial Control in m -frame:

$$X^m + v_X^m = P^m + R_c^m(\Gamma) \cdot (A^c + N^c) + S^m - M(s_l^m) \cdot R_l^m(\eta) \cdot (V^l + v_V^l) \cdot \delta t$$

$$R_c^m(\Gamma) = R_l^m(\eta) \cdot R_b^l(\chi + v_\chi) \cdot R_c^b$$

Blázquez, M., Colomina, I., 2012. On INS/GNSS-based time synchronization in photogrammetric and remote sensing multi-sensor systems. PFG Photogrammetrie, Fernerkundung, Geoinformation, 2012 (2): 91 - 104. EuroCOW 2012.

THE SPACE-TIME NETWORK GEOMETRY

EFFECT OF A CONSTANT SYNCHRONIZATION ERROR

- In general scenarios:

Effect of a constant synchronization error Δt :

3D error $\Delta t \cdot V(t)$ in aerial control position coordinates at time t

- In typical aerial photogrammetric mission and within a strip:

$V(t) = (v_E(t), v_N(t), v_h(t))^T$ is almost constant.

$v_h(t) \approx 0$

Images are horizontally stabilized.

Effect of a constant synchronization error Δt :

horizontal shift $\Delta t \cdot (v_E(t), v_N(t))^T$

- Velocity dependent impact.
- Independent of the flying height.
- Strip sense-dependent.

SPACE-TIME NET GEOMETRY = SPACE NET GEOMETRY + TIME

- VARIABLE velocity, "classical space network geometry" CANNOT calibrate Δt .
- CONSTANT velocity, Δt behaves similarly to:
 - the ground shift of an error in the principal point $(\Delta x_0, \Delta y_0)^T$,
 - the effect of an error in the lever-arms or INS/GNSS aerial control position.

	Spatio \ Temporal	Time calibration
Orientation	Exterior Orientation Tie Point	✓ ✓
System Calibration	Lever Arms Boresight Matrix GNSS Shift Correction	known ✓ ?
Camera calibration	Camera Nodal Vector Self-Calibration Camera cnst. & PP	known ✓ ?

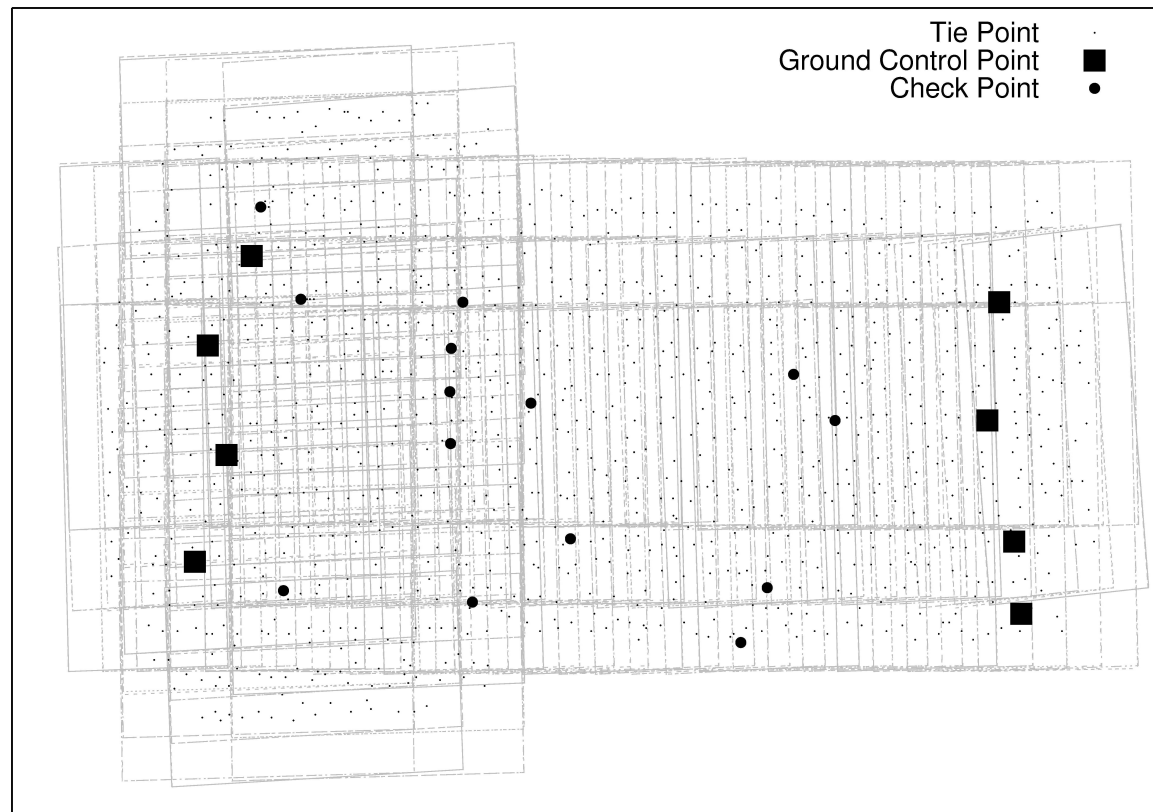
SPACE-TIME NETWORK GEOMETRY CONFIGURATIONS

	Block Strip Configuration	Block Velocity Configuration	Camera Calibration	Time Calibration	INS/GNSS Correction
a	alt. fly. sense	vel. diff. within strips	no	one δt	S^m /strip
b	alt. fly. sense	vel. cnst. in block	no	one δt	S^m /block
c	alt. fly. sense & cross-strips	vel. cnst. among strips	$(\delta x_0, \delta y_0)$	one δt	S^m /block
d	alt. fly. sense & 2 blocks diff. alt.	vel. cnst. within blocks	$(\delta x_0, \delta y_0)$	one δt	S^m /block
e	alt. fly. sense & 2 blocks diff. alt.	vel. cnst. within blocks	$(\delta f, \delta x_0, \delta y_0)$	one δt	one S^m

CONCEPT VALIDATION

VAIHINGEN/ENZ-7 BLOCK

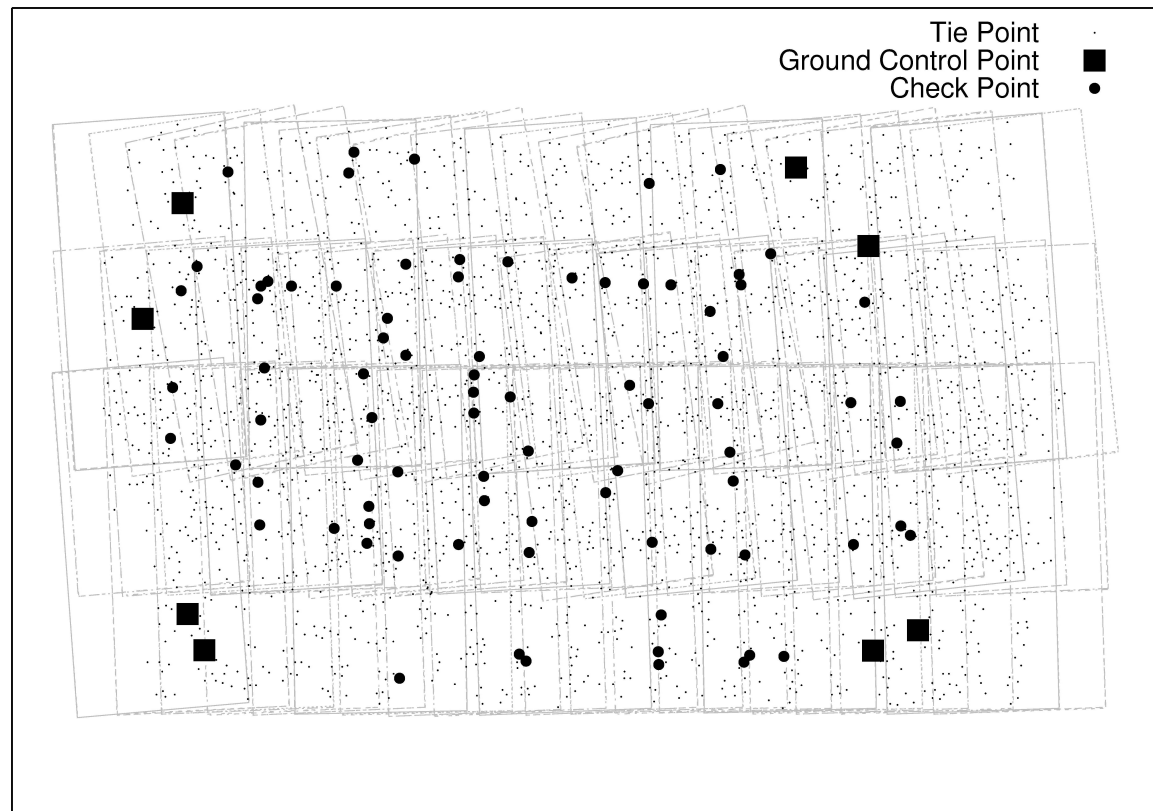
1:14000 60%x76% h=1150 m GSD=10 cm 7910 ic 8 GCPs 14 CPs 120x2 DDC-H/39 images 1106 TPs



Std ic: $x,y=1.4\mu\text{m}$ GCP: E,N,h=2cm INS/GNSS: E,N=3.5cm h=5.5cm $v_e,v_n,v_u=5\text{ mm/s}$ $r,p=5$ h=8 mdeg

VAIHINGEN/ENZ-20 BLOCK

1:33500 60%x64% h=2750 m GSD=23 cm 11781 ic 8 GCPs 85 CPs 600x2 DDC-H/39 images 2258 TPs



Std ic: $x,y=1.4\mu\text{m}$ GCP: E,N,h=2cm INS/GNSS: E,N=3.5cm h=5.5cm $v_e,v_n,v_u=5\text{ mm/s}$ $r,p=5$ h=8 mdeg

BLOCK CHARACTERISTICS

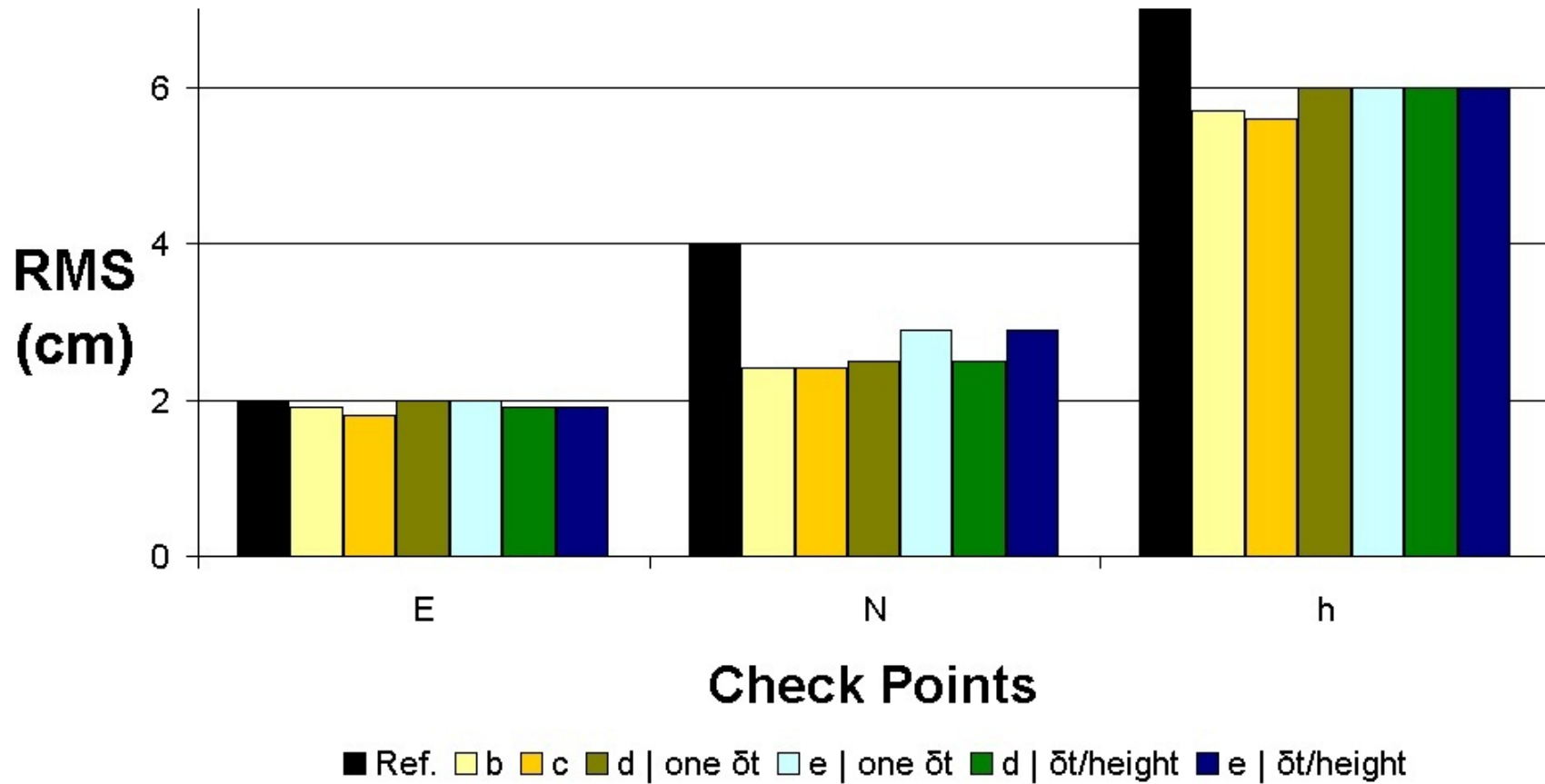
- The IGI Dual-DigiCAM-H/39 system is well synchronized:
 - no significant δt values are expected,
 - no impact in accuracy and precision due to the tPVA INS/GNSS models is expected.
- Difference between initial (manufacturer's convention) and mid (our convention) exposure time \Rightarrow a constant δt depending on the flying height:
 - to half of $1/800$ s, it means, $\delta t = 0.625$ ms for the V-7 block,
 - to half of $1/350$ s, it means, $\delta t = 1.429$ ms for the V-20 block.
- The available data and the knowledge of the system lead us:
 - to use V-7 and/or V-20 for testing some block configurations,
 - to create a combined block V-7-20 for testing other block configurations,
 - to estimate a different δt parameter for each block.

BLOCK CONFIGURATIONS

	Block Strip Configuration	Block Velocity Configuration	Camera Calibration	Time Calibration	INS/GNSS Correction	Test Block
a	alt. fly. sense	vel. diff. within strips	no	one δt	S^m /strip	–
b	alt. fly. sense	vel. cnst. in block	no	one δt	S^m /block	V-7 V-20
c	alt. fly. sense & cross-strips	vel. cnst. among strips	$(\delta x_0, \delta y_0)$	one δt	S^m /block	V-7 V-20
d	alt. fly. sense & 2 blocks diff. alt.	vel. cnst. within blocks	$(\delta x_0, \delta y_0)$	one δt or δt /block	S^m /block	V-7-20
e	alt. fly. sense & 2 blocks diff. alt.	vel. cnst. within blocks	$(\delta f, \delta x_0, \delta y_0)$	one δt or δt /block	one S^m	V-7-20

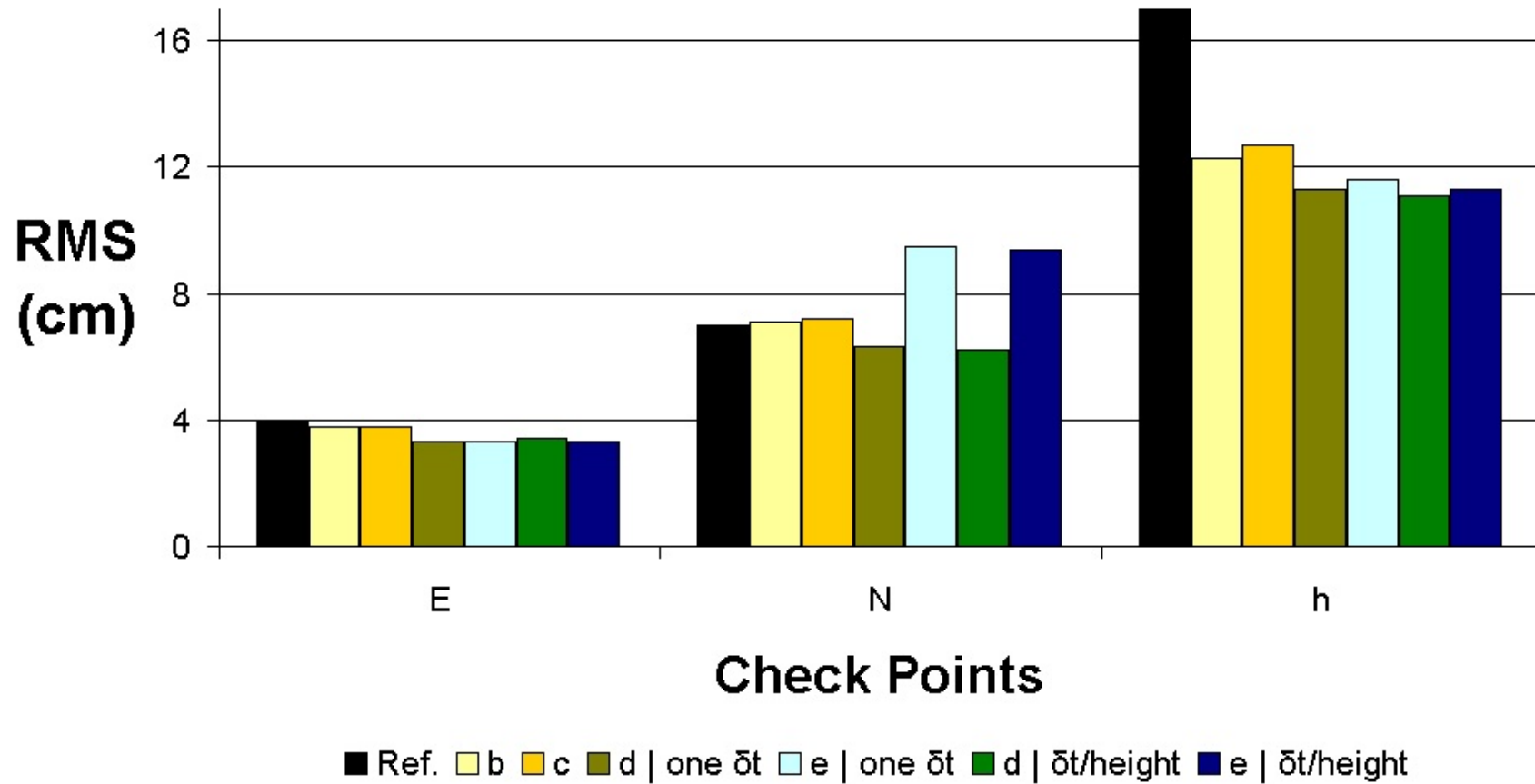
V-7 ACCURACY RESULTS

ACCURACY V-7



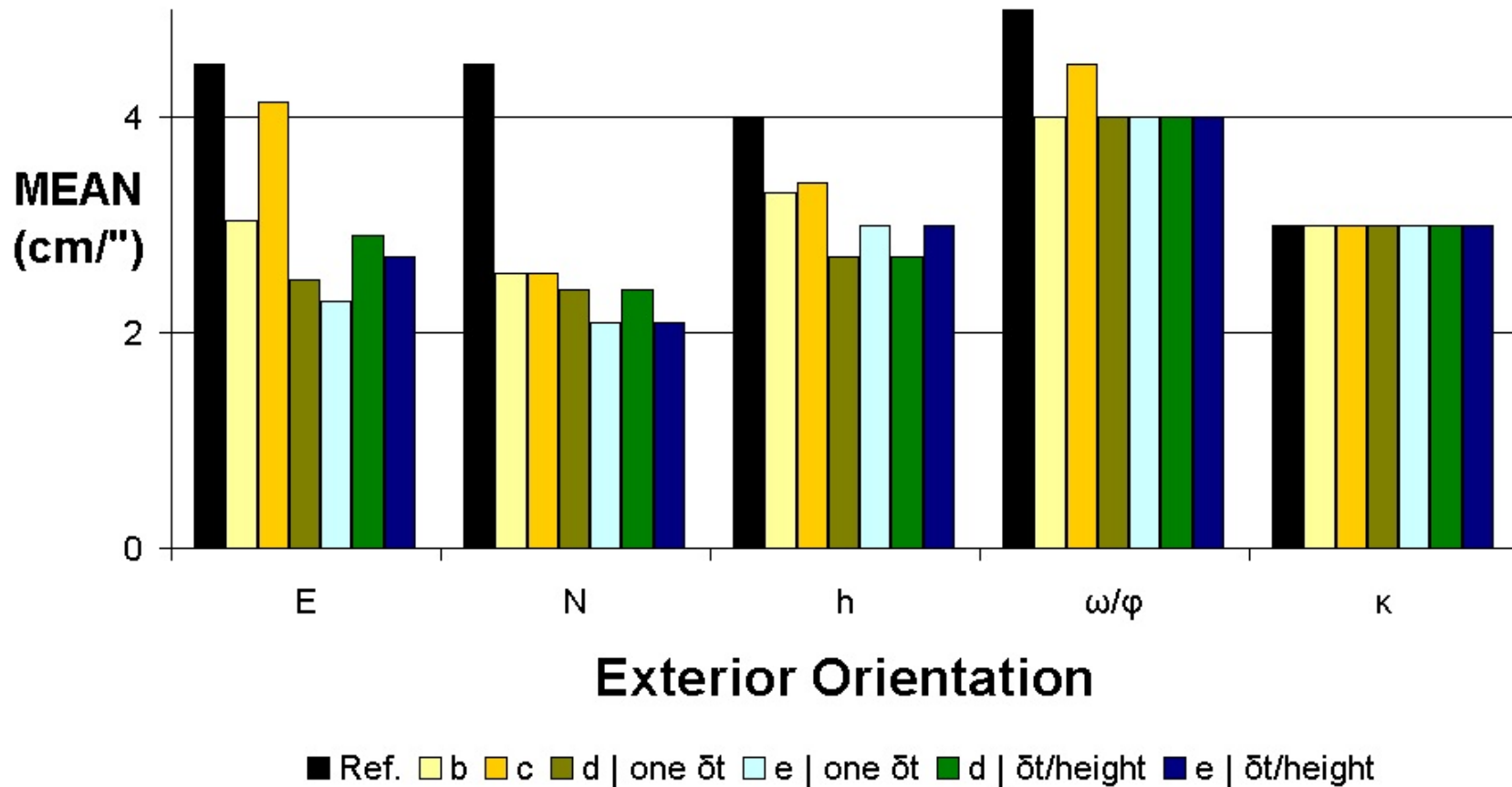
V-20 ACCURACY RESULTS

ACCURACY V-20



V-7 & V-20 PRECISION RESULTS

PRECISION Std V-7 & V-20



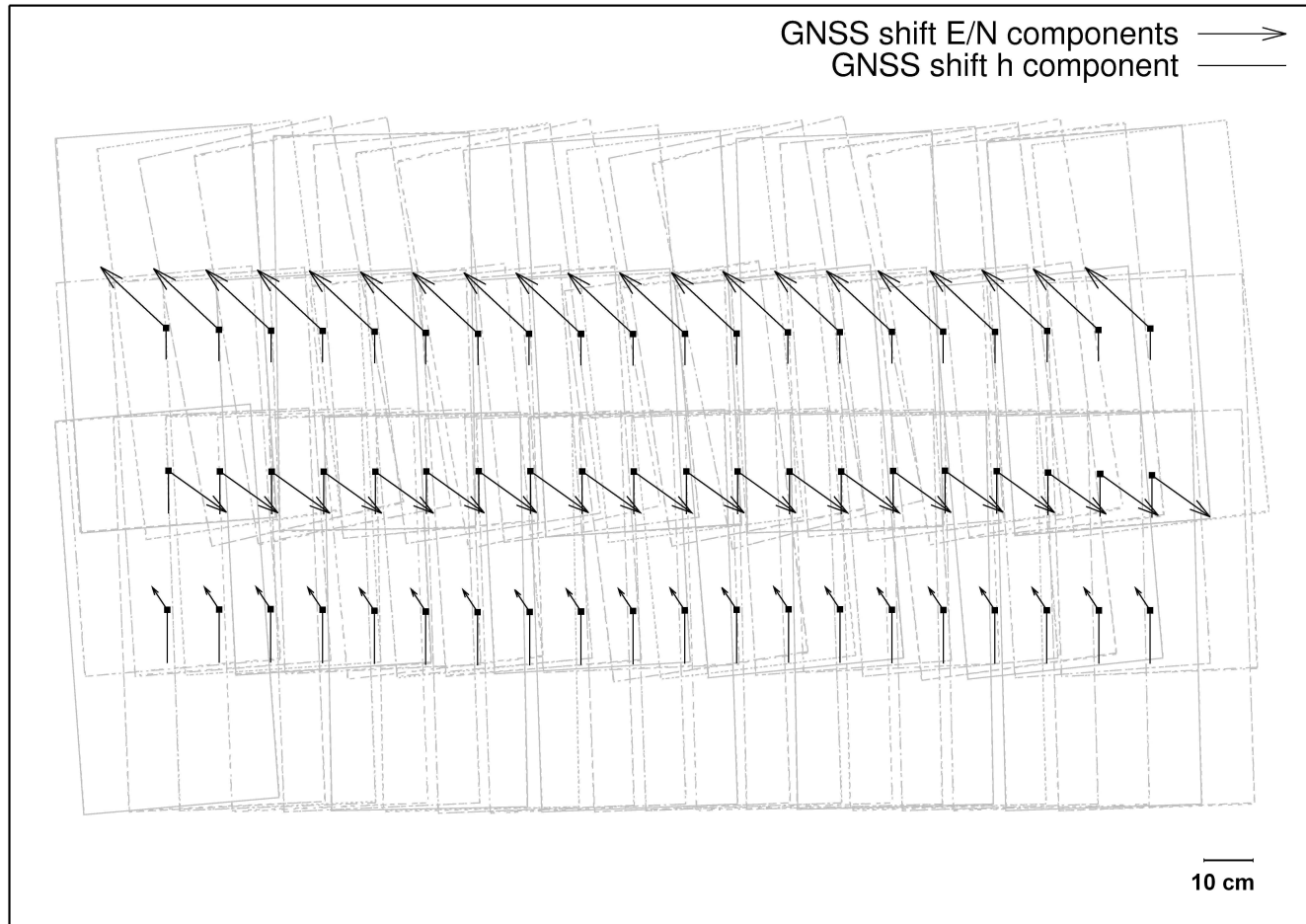
TIME CALIBRATION DETERMINABILITY

	Camera Calibration	Time Calibration	INS/GNSS Correction	Test Block	$\rho(\delta t, -)$	$b(\delta t)$	δt Det.
b	no	one δt	S^m /block	V-7	≤ 0.7	0.934	✓
				V-20	≤ 0.7	0.984	✓
c	$(\delta x_0, \delta y_0)$	one δt	S^m /block	V-7	≤ 0.7	0.961	✓
				V-20	$\rho(\delta t, \delta x_0) = 0.8$	0.996	✗
d	$(\delta x_0, \delta y_0)$	one δt	S^m /block	V-7-20	≤ 0.7	0.956	✓
		δt /block			≤ 0.7	0.950	✓
						0.986	
e	$(\delta f, \delta x_0, \delta y_0)$	one δt	one S^m	V-7-20	≤ 0.7	0.945	✓
		δt /block			≤ 0.7	0.943	✓
						0.986	

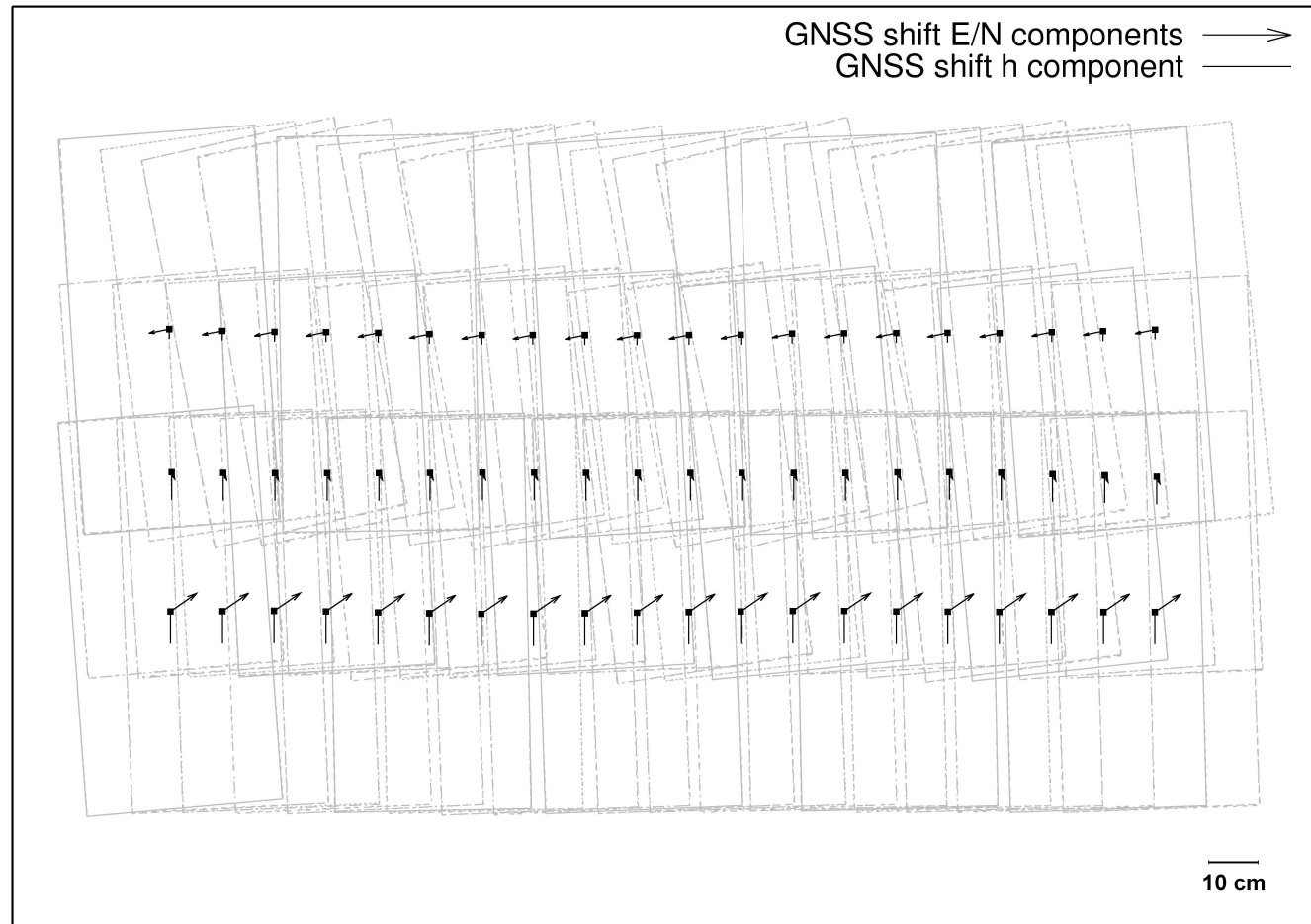
PRECISION & DETERMINABILITY RESULTS

	Test Block	Camera Calibration (μm)			INS/GNSS Correction (cm)			Time Calibration (ms)
		δf	δx_0	δy_0	s_E	s_N	s_h	δt
b	V-7	–	–	–	-0.1 ± 1.0	-2.5 ± 1.0	2.7 ± 1.5	-0.1 ± 0.1
b	V-20	–	–	–	0.5 ± 1.8	3.5 ± 2.1	-3.1 ± 4.4	1.4 ± 0.4
c	V-7	–	-2 ± 1 5 ± 2	14 ± 1 -10 ± 1	0.0 ± 1.0	-2.5 ± 1.0	4.5 ± 1.5	0.0 ± 0.2
d	V-7-20	–	-3 ± 1 -4 ± 1	11 ± 1 -1 ± 1	-0.0 ± 1.0 1.6 ± 1.8	-2.7 ± 1.0 6.1 ± 2.1	2.6 ± 1.6 -0.1 ± 3.9	-0.5 ± 0.1
d	V-7-20	–	1 ± 1 -1 ± 1	11 ± 1 -1 ± 1	-0.4 ± 1.0 0.8 ± 1.8	-2.6 ± 1.0 6.1 ± 2.1	2.7 ± 1.6 -0.3 ± 3.9	0.0 ± 0.2 1.4 ± 0.4
e	V-7-20	-2 ± 2 0 ± 2	-4 ± 1 -3 ± 1	12 ± 1 -3 ± 1	0.3 ± 0.9	-1.1 ± 0.9	4.1 ± 2.6	-0.5 ± 0.1
e	V-7-20	-2 ± 2 0 ± 2	0 ± 1 0 ± 1	12 ± 1 -3 ± 1	-0.1 ± 0.9	-1.0 ± 0.9	4.4 ± 2.6	0.0 ± 0.2 1.3 ± 0.4

BEFORE ...



... AFTER



SUMMARY OF THE RESULTS

- The IGI Dual-DigiCAM-H/39 system is well synchronized.
- Best results in configurations b (no camera calibration) and d (pp correction):
 - accuracy and precision is achieved,
 - δt is determinable,
 - known δt values are recovered with one different δt parameter per block.
- "tPVA ISO + conf. b" vs "tPA ISO + one linear GNSS shift per strip":
 - "tPVA + conf. b" estimates 4 (1 + 3) parameters vs 18 or 9 (3 x n strips) for V-7 and V-20 respectively,
 - "tPVA + conf. b" explicitly models and estimates the constant time shift.
- Configuration c cannot be fully validated with the available data.
- Configuration e for the available data:
 - estimates the δt , camera constant and principal point corrections parameters, but
 - make worse the accuracy results for the V-20 block.

GENERAL CONCLUSIONS

- We propose a method to estimate a constant δt synchronization parameter based on:
 - the use of INS/GNSS velocities [presented mathematical models],
 - decorrelation of other estimated parameters [discussed space-time net geometries].
- We validated this method using the Vaihigen/Enz blocks.
- The method can be applied to other acquisition instruments.
- Scenarios for the proposed time calibration method:
 - manufacturer's side for system verification and calibration purposes;
 - end users for high demanding specifications, the need to verify the system performance, pre-calibration for DiSO, ...

ACKNOWLEDGEMENTS

- GeoNumerics (Barcelona, Spain) for making its generic adjustment platform GENA available.
- Dr. Jens Kremer (IGI Ingenieurgesellschaft für Interfaces mbH, Kreuztal, Germany) and Dr. Michael Cramer (Institut für Photogrammetrie, Universität Stuttgart, Germany) for making the Vaihingen/Enz gsd7 block data available.

Reference: Blázquez, M., Colomina, I., 2012. On INS/GNSS-based time synchronization in photogrammetric and remote sensing multi-sensor systems. PFG Photogrammetrie, Fernerkundung, Geoinformation, Vol. 2012, No. 2, pp. 91-104.

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