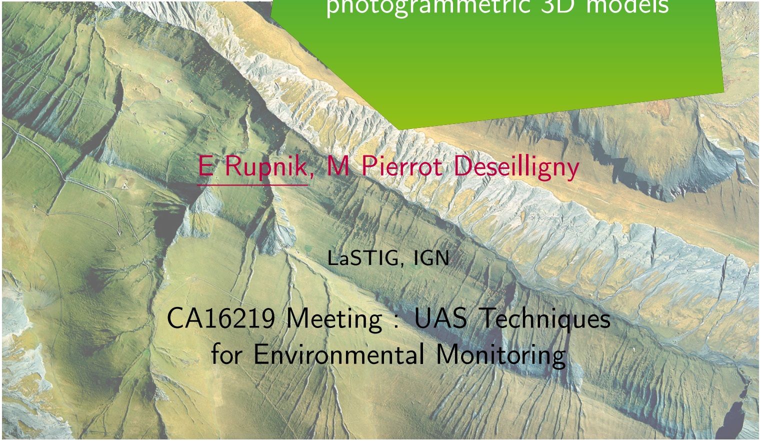
INSTITUT NATIONAL
DE L'INFORMATION
GÉOGRAPHIQUE
ET FORESTIÈRE

Accuracy estimation and optimization of UAV photogrammetric 3D models



E Rupnik, M Pierrot Deseilligny

LaSTIG, IGN

CA16219 Meeting : UAS Techniques for Environmental Monitoring

UAV-photogrammetry pipeline

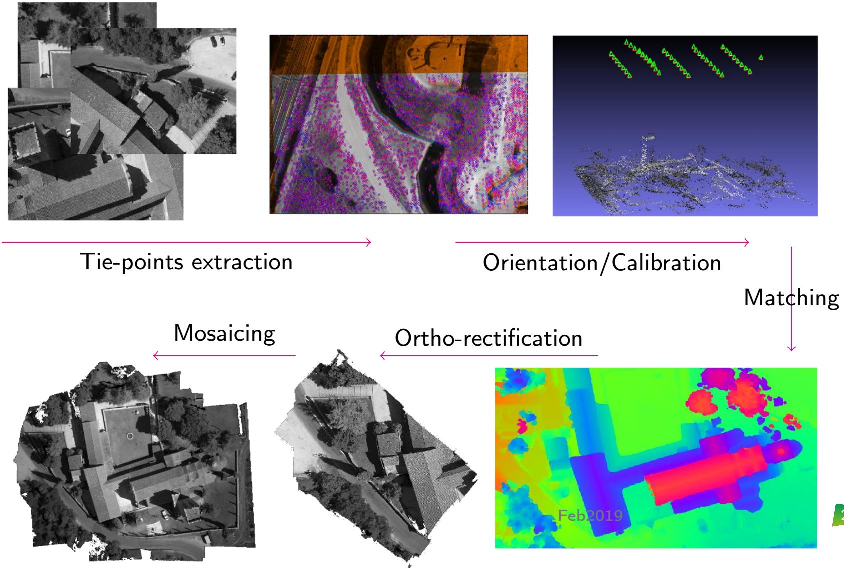
Quality Analysis

- Relative orientation
- Absolute orientation
- Matching quality evaluation
  - With dense ground truth
  - W/o dense ground truth, qualitative
  - W/o dense ground truth, quantitative

UAV-related research at IGN

- Hardware
- Algorithms

UAV-photogrammetry pipeline



Quality Analysis

1. What do we want to evaluate?:
   - only the 3D model
   - orientations
   - intermediary parameters (e.g., internal parameters)

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   - orientations
   - intermediary parameters (e.g., internal parameters)
2. What Ground Truth is at disposal (i.e., dense)?
3. What metric to use?

UAV-photogrammetry pipeline

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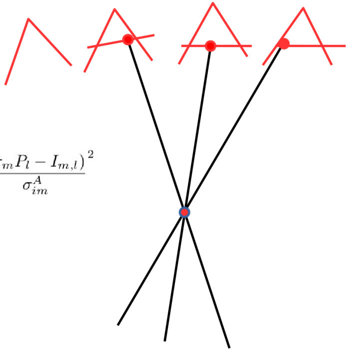
Relative orientation quality estimation

Classical measures:

- tie-points reprojection error (BBA σ)
- % of tie-points retained during BBA



$$\sum_{l=1}^{Q}\sum_{m=1}^{n_l}\frac{(\pi_m P_l - I_{m,l})^2}{\sigma_{im}^A}$$

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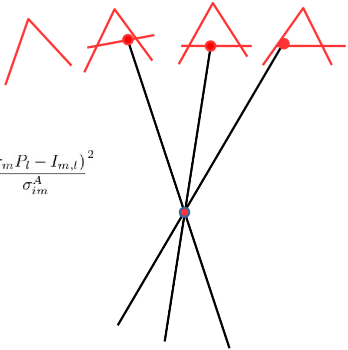

Disadvantage

- combines 2 error types
  - measurement error (white noise, not an issue)
  - camera modelling error (systematic, can generate bias)

Relative orientation quality estimation

An alternative measure (also in MicMac):

- dense matching in 2 directions, i.e., epipolar and transverse (y-parallax)

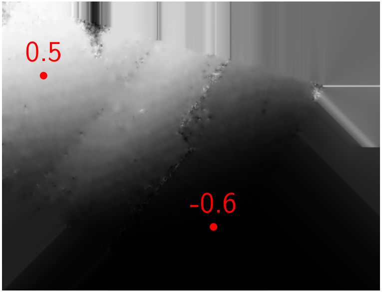

Figure: Y-parallax with high systematism.

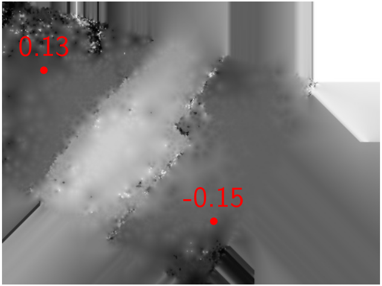

Figure: Y-parallax with low systematism.

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Absolute orientation quality estimation

- Use Ground Control Points to evaluate accuracy

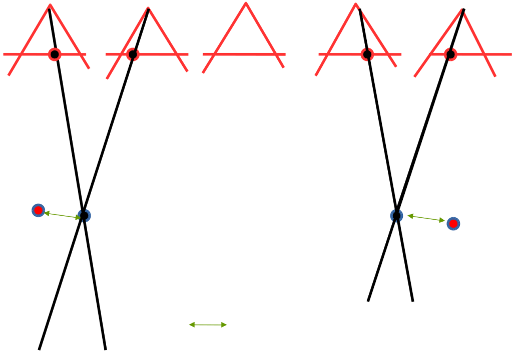
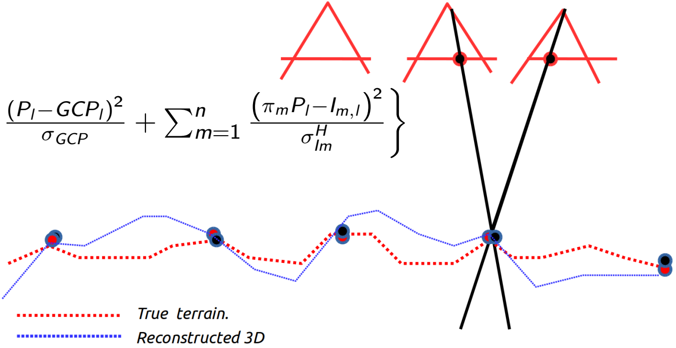


Figure: Accuracy measure - distances between 3D position predicted by photogrammetry and its *true* position.

Absolute orientation quality estimation

1. There is many more degrees of freedom (at least 6 per image) than there is constraints
2. if σ_{GCP} and σ_{Im} are set to low values, the system will *learn by heart* on the training set with risk of severe extrapolation outside the set.

$$\sum_{l=1}^{O}\left\{\frac{(P_l-GCP_l)^2}{\sigma_{GCP}}+\sum_{m=1}^{n}\frac{\left(\pi_m P_l-I_{m,l}\right)^2}{\sigma_{Im}^{H}}\right\}$$



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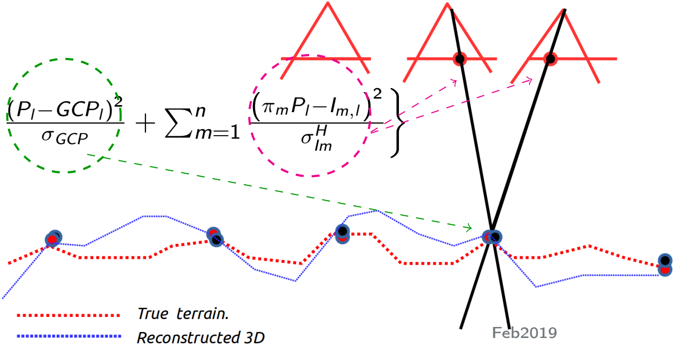

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2. if σ_{GCP} and σ_{Im} are set to low values, the system will *learn by heart* on the training set with risk of severe extrapolation outside the set.

Good practice, do not

- use all GCPs in the BBA
- evaluate the accuracy on the GCPs participating in the BBA

Absolute orientation quality estimation

Rules-of-thumb for evaluating accuracy given σ_{GCP} and σ_{Im}:

Absolute orientation quality estimation

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Absolute orientation quality estimation

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1. with many points: Split the points into two separate groups, e.g., if 20 points available, use 10 as GCPs and the other 10 as CPs (Check Point)
2. with few points, e.g., 6: Perform 6 independent computations where at each instance a GCP is alternatively removed and used as CP. Calculate final accuracy as an average of all 6 results.

Absolute orientation quality estimation

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2. with few points, e.g., 6: Perform 6 independent computations where at each instance a GCP is alternatively removed and used as CP. Calculate final accuracy as an average of all 6 results.
3. with minimum no of points, e.g., 4: perform a Helmert transformation and estimate the accuracy empirically taking into account the degree of freedom; e.g. if $\sigma = 3cm$ then $\sigma_{emp} = \sigma \cdot \frac{12}{5} = 7.2cm$

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Matching quality evaluation
With dense ground truth

- Two very different DSMs?

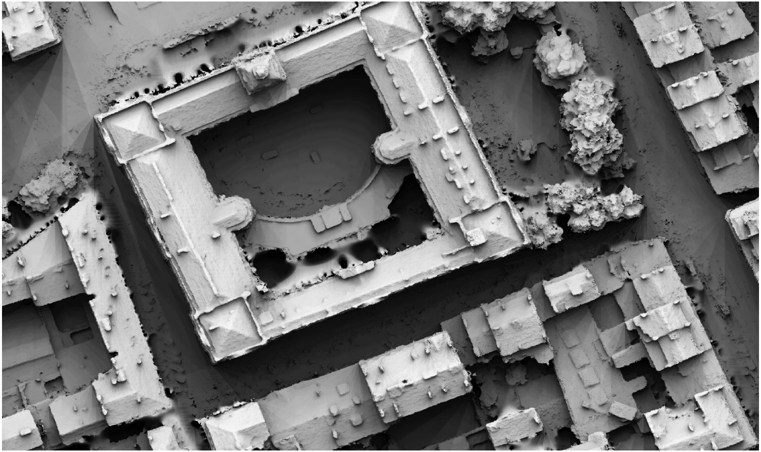


Figure: DSM1, EuroSDR benchmark

Matching quality evaluation
With dense ground truth

- Two very different DSMs?

Figure: DSM2, EuroSDR benchmark

Matching quality evaluation
With dense ground truth

- Two very different DSMs?

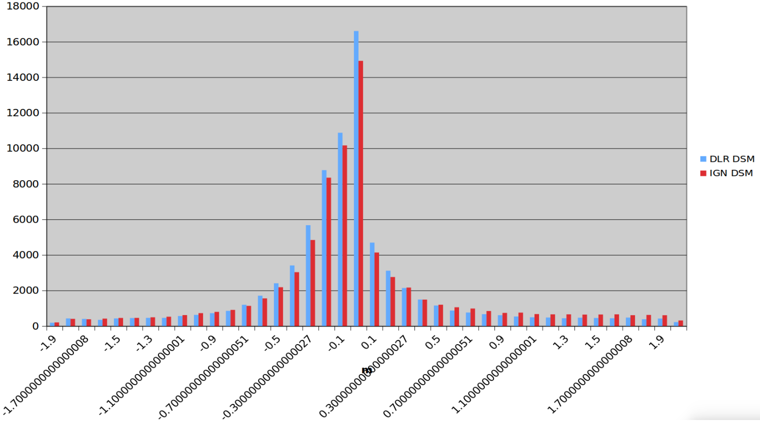


Figure: Δh of DSM1 and DSM2 wrt a Ground Truth

Matching quality evaluation
with dense ground truth

- Even more complicated, what do we evaluate?

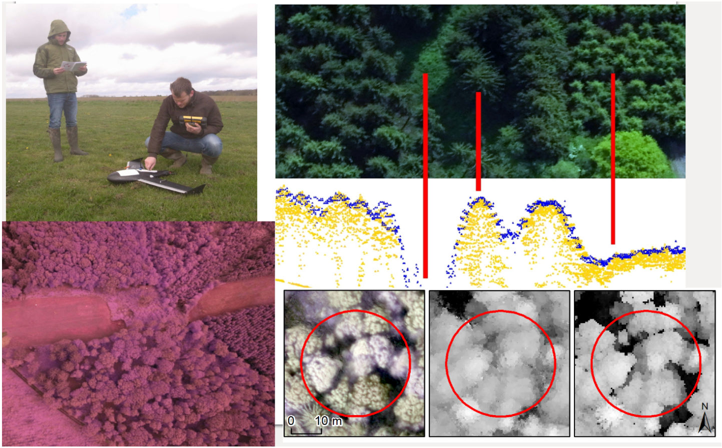


Figure: Photogrammetry in forestry applications.

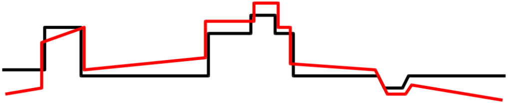
Matching quality evaluation
With dense ground truth

- The errors should be separated into:

Matching quality evaluation
With dense ground truth

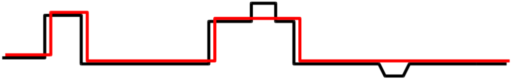
- The errors should be separated into:

Bias (due to orientation)

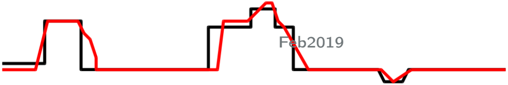


Random noise

Generalization



Contour alignment



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UAV-related research at IGN

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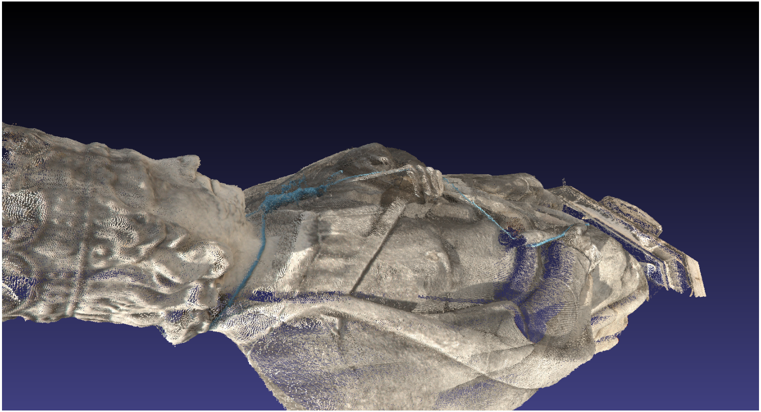
Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Yes but not on the coloured pointcloud!



Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. A depth map?

Matching quality evaluation
W/o dense ground truth, qualitative

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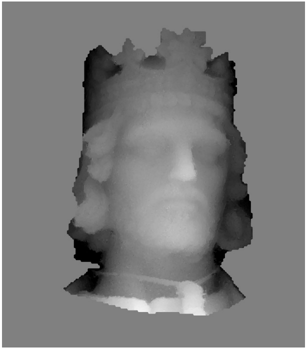
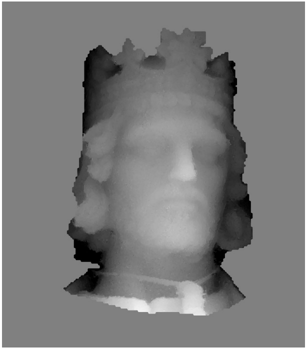


Figure: Regul $\alpha \approx 0.01$

Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. A depth map? No!



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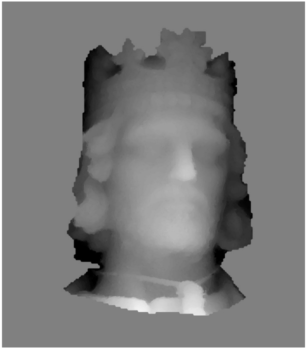
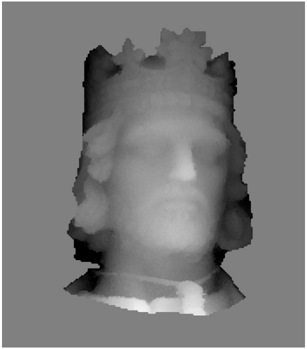


Figure: Regul $\alpha \approx 0.05$

Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. A depth map? No!



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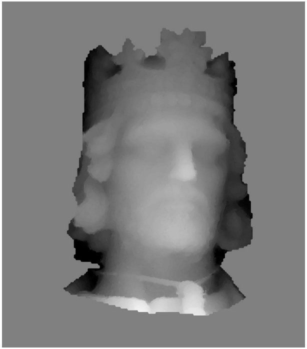

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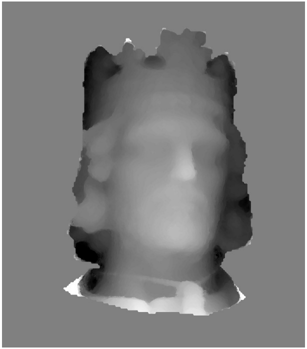


Figure: Regul $\alpha \approx 0.1$

Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Grayshading?

Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Grayshading? Yes!

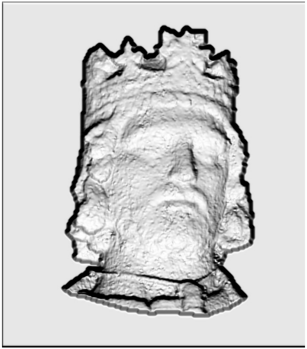


Figure: Regul $\alpha \approx 0.01$

Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Grayshading? Yes!

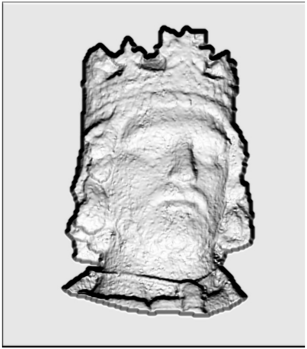
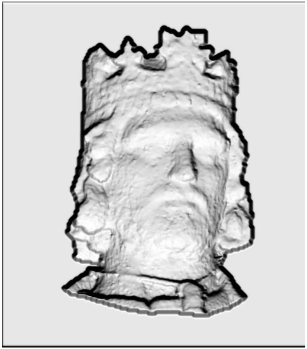


Figure: Regul $\alpha \approx 0.01$



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Matching quality evaluation
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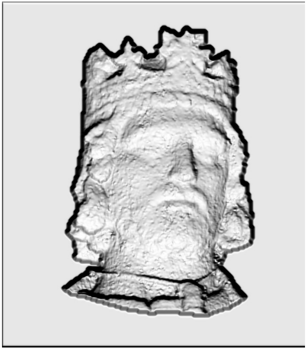
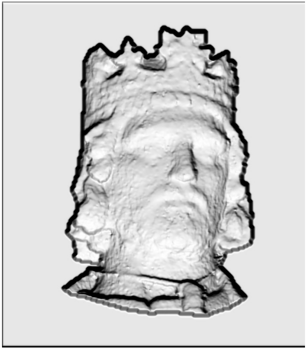


Figure: Regul $\alpha \approx 0.01$



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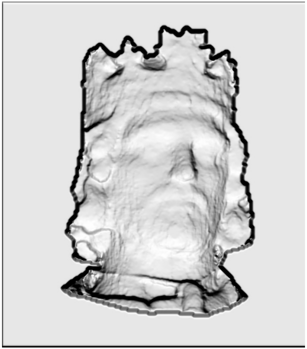


Figure: Regul $\alpha \approx 0.1$

Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Color-coded depth?

- Visual inspection. Color-coded depth? Perfect 3D model?

Figure: Master image.

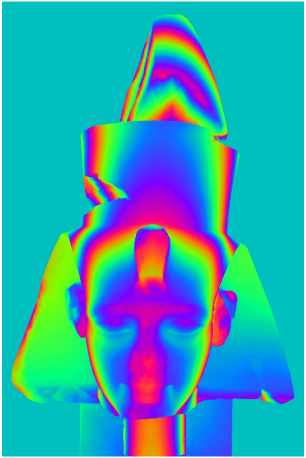
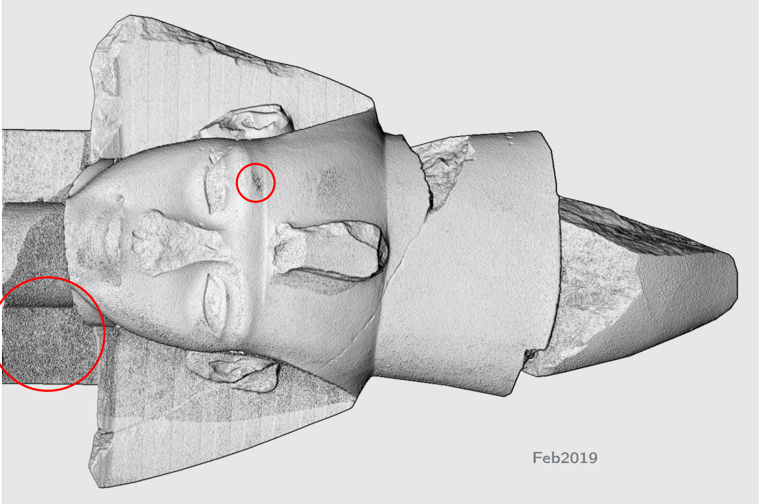


Figure: Color-coded DSM.

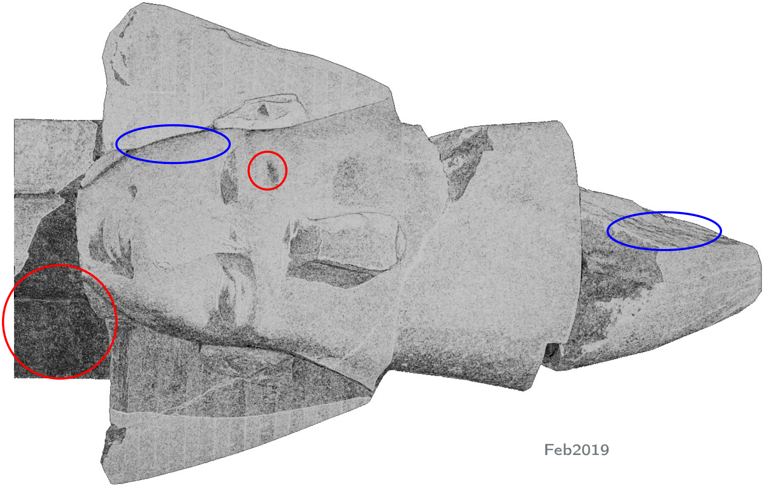
Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Grayshading, again, reveals the quality.



Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Correlation score as a quality indicator.



Matching quality evaluation
W/o dense ground truth, qualitative

- Visual inspection. Understanding poor correlation scores.

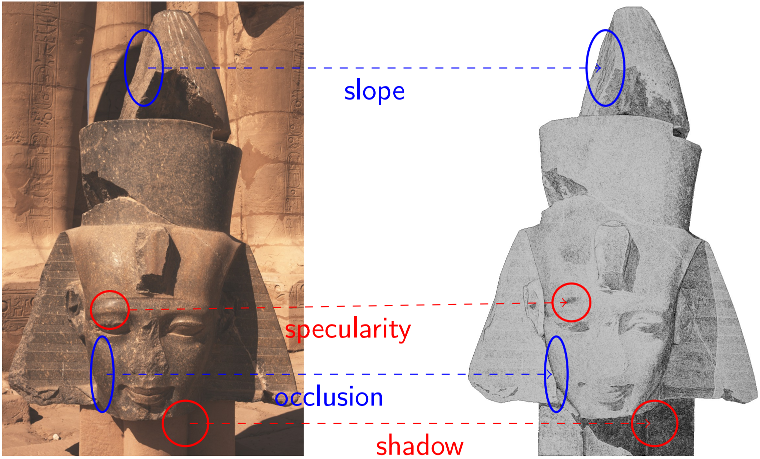


Figure: Master image.

Figure: Corr image.

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UAV-related research at IGN

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Matching quality evaluation
W/o dense ground truth, quantitative

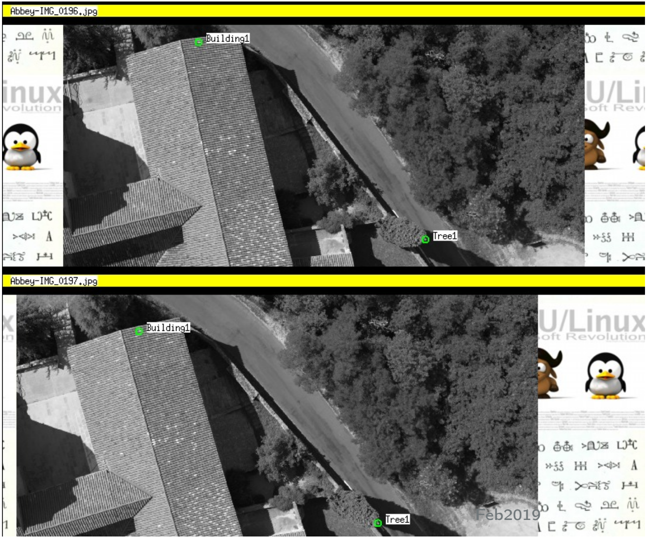
1. With many ground GPS points :

2. With stereo restitution :

Matching quality evaluation
W/o dense ground truth, quantitative

1. With many ground GPS points :
   - + bias in Z-coordinate due to orientation
   - +– random noise
   - – generalization and misalignment
   - – access difficulty (e.g., trees, buildings)
2. With stereo restitution :
   - + any identifiable points can serve control
   - + no need for field measurements, complementary control
   - + bias in XYZ-coordinate
   - +– random noise
   - – need to dispose of good orientations
   - – manual labour

Matching quality evaluation
W/o dense ground truth, quantitative



Matching quality evaluation
Bilans

Error type	CP	GPS point	Reconstructed 3D	Shaded/Correl map
Bias in X, Y	✓			
Bias in Z	✓	✓		
Random noise		✓	✓	✓
Generalization			✓	✓
Misalignment			✓	✓

Table: Error detectability.

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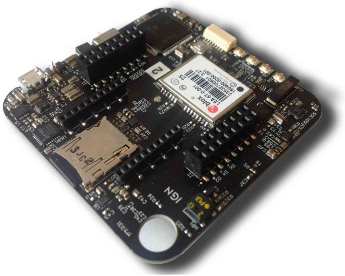
CamLIGHT:

- HR resolution
- global shutter
- weight $\approx$ 300g (lens dependent)
- metric camera
- operational in multi-sensor modes

UAV-related research at IGN
Hardware

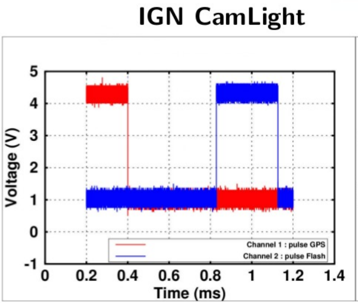
CamLIGHT:

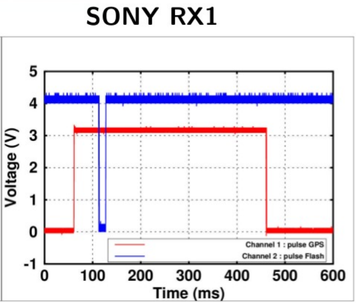
- HR resolution
- global shutter
- weight $\approx$ 300g (lens dependent)
- metric camera
- operational in multi-sensor modes
- equipped with GPS ublox module
- accurate synchronisation



UAV-related research at IGN
Hardware

Time synchronization of sensors : **Amplitude**





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Selected contributions:

- Lever arm modelling, [1]
- Thermal effect modelling, [2]
- New camera models, [3]
- New tie-points computation, [4]

Lever arm modelling, [1]

- self-calibration method
- GCPs indispensable
- ≈1cm accuracy with 1GCP, evaluation on many CPs

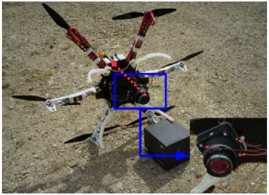


Table 1
Residuals on check points depending on processing strategies.

	Estimated parameters				MAE[a] (cm/px)	s[b] (cm)
	Relative poses	Absolute centers	Lever-arm	Camera model		
$\mathcal{S}_1$	(Section 4.1)	(Section 4.2)	(Section 4.4)	(Section 4.1)	2.4/2.0	0.8
$\mathcal{S}_2$	Tightly coupled	Tightly coupled	–	–	0.8/0.7	0.8
$\mathcal{S}_3$	Tightly coupled	Tightly coupled	Tightly coupled	–	0.8/0.7	0.8
$\mathcal{S}_4$	Tightly coupled	Tightly coupled	–	Tightly coupled	0.8/0.7	0.7
$\mathcal{S}_5$	Tightly coupled	Tightly coupled	Tightly coupled	Tightly coupled	0.8/0.7	0.8

[a] Mean Absolute Error.
[b] Standard Deviation.

Thermal deformation modelling, [2]

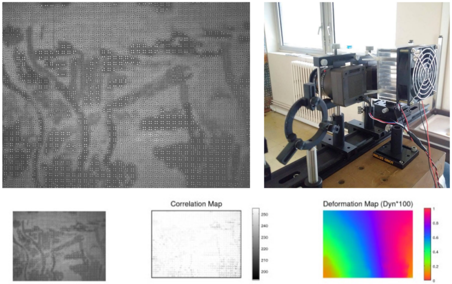


Figure: The experiment. Top: calibration field, the camera and the heater. Bottom: inter-epoch correlation and deformation maps.

Thermal deformation modelling, [2]

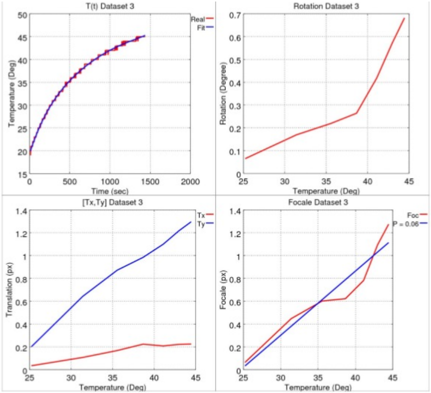


Figure: Temperature ranges and the deformations decomposed into: rotation, translation and focal length variation.

Thermal deformation modelling, [2]

Nom Point	Images Brutes	Images Corrigées	Ratio C/R
Pt_1 (mm)	5.3	0.2	24
Pt_2 (mm)	5.2	0.9	5
Pt_3 (mm)	5.4	0.7	7
Pt_4 (mm)	4.4	1.9	2
Pt_5 (mm)	5.9	1.6	3
Pt_6 (mm)	4.6	1.1	4
Pt_7 (mm)	5.2	0.1	390
Pt_8 (mm)	5.6	0.1	82
Pt_9 (mm)	5.0	0.6	7
Pt_{10} (mm)	5.5	0.1	36
Moyenne (mm)	**5.2**	**0.7**	**7**

Figure: Residuals on CPs without and with the thermal correction.

New camera models, [3]

- finer precision camera modelling

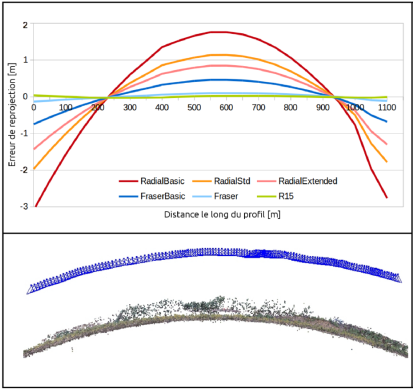
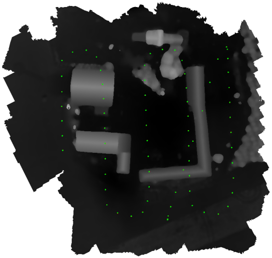


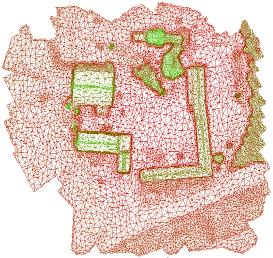
Figure: The *bending effect* with different camera models.

Tie points computation, [4]

- more precise image measurements
- high manifold
- more homogeneous distribution

2nd iteration photogrammetry : use a rough 3D model to guide the detection of new, better tie-points.





Tie points computation, [4]

- more precise image measurements
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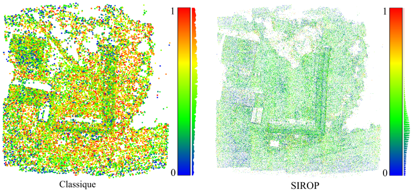

Figure: Tie-points color-coded with residuals. Left: SIFT, right: new tie-points.

Tie points computation, [4]

- more precise image measurements
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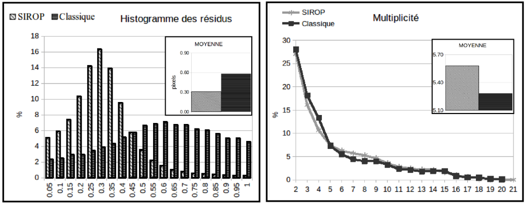

Figure: Left: histogram of residuals for SIFT and new tie-points; right: respective points multiplicities.

CFPT 2019: Conférence Française de Photogrammétrie et de Télédétection

Rouen - 27-29 août 2019

Ewelina Rupnik

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BIENVENUE SUR LE SITE OFFICIEL DE LA CONFÉRENCE CFPT 2019

Du **27 au 29 août 2019**, la SFPT (Société Française de Photogrammétrie et de Télédétection) organise sur le campus de l'INSA à Rouen (76) sa conférence annuelle.

Nous chercherons à faire un état des lieux des recherches récentes en reconnaissance des formes et perception / vision par ordinateur, métrologie, photogrammétrie et télédétection. Ces recherches peuvent être de natures diverses: méthodologiques, théoriques ou expérimentales, développement d'algorithmes, conception d'outils, de systèmes ou d'applications.

Le mardi 27 août sera consacré à des tutoriaux. La conférence se tiendra les 28 et 29 août.

DATES IMPORTANTES

- **Soumission des papiers longs**: 19 avril
- **Soumission des papiers courts**: 13 mai

APPEL AUX TUTORIAUX

Des tutoriaux seront organisés le 27 août. Les propositions sous forme de cours ou de manipulation de logiciels (1/2 ou 1 journée entière) sont à soumettre à ewelina.rupnik@ign.fr avant le **6 mai 2019**.

[1] M Daakir, Marc Pierrot-Deseilligny, Pierre Bosser, Francis Pichard, Christian Thom, Yohann Rabot, and Olivier Martin.
Lightweight uav with on-board photogrammetry and single-frequency gps positioning for metrology applications.
ISPRS Journal of Photogrammetry and Remote Sensing, 127:115–126, 2017.

[2] M Daakir, Y Zhou, M Pierrot Deseilligny, C Thom, O Martin, and E Rupnik.
Improvement of photogrammetric accuracy by modeling and correcting the thermal effect on camera calibration.
ISPRS Journal of Photogrammetry and Remote Sensing, 148:142–155, 2019.

[3] V Tournadrea, M Pierrot-Deseilligny, and PH Faure.
Uav linear photogrammetry.
International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 40, 2015.

[4] Nguyen Truong Giang, Jean-Michaël Muller, Ewelina Rupnik, Christian Thom, and Marc Pierrot-Deseilligny.
Second iteration of photogrammetric processing to refine image orientation with improved tie-points.
Sensors, 18(7):2150, 2018.

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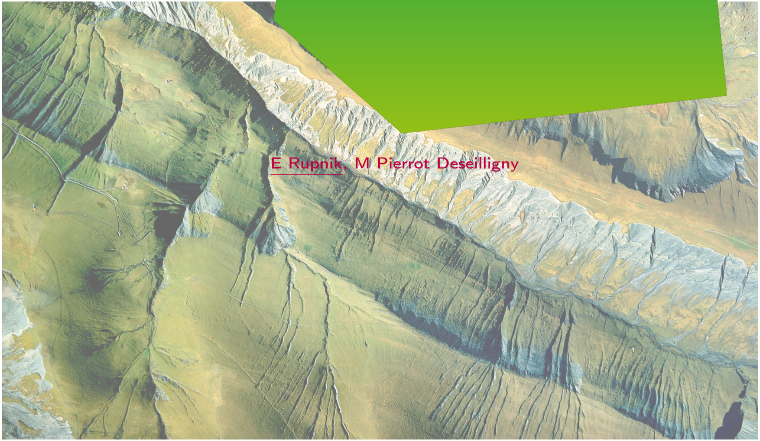
Thank you for your attention!



E Rupnik, M Pierrot Deseilligny