



To Bundle Adjust or Not: A Comparison of Relative Geolocation Correction Strategies for Satellite Multi-View Stereo



Roger Marí, Carlo de Franchis, Enric Meinhardt-Llopis, and Gabriele Facciolo CMLA, ENS Paris-Saclay, 94235 Cachan, France

Objective

- Investigate relative geolocation correction techniques for satellite RPC camera models, i.e. compare Bundle Adjustment (BA) image based methods to geometry based methods.
- Analyze impact on Multi-View Stereo (MVS) 3D reconstructions from satellite imagery.

Relative geolocation correction techniques

3 methods are considered:

 NCC DSM alignment: Omit prior BA and directly align independent DSMs u and v via a 3D translation that maximizes the Normalized Cross Correlation (NCC) between them.

$$NCC(\mathbf{u}, \mathbf{v}) := \frac{1}{|\widehat{\Omega}|} \sum_{\mathbf{t} \in \widehat{\Omega}} \frac{(\mathbf{u}_{t} - \mu_{\mathbf{u}}(\widehat{\Omega}))(\mathbf{v}_{t} - \mu_{\mathbf{v}}(\widehat{\Omega}))}{\sigma_{\mathbf{u}}(\widehat{\Omega})\sigma_{\mathbf{v}}(\widehat{\Omega})}, \tag{1}$$

where $\widehat{\Omega}:=\Omega_{\mathbf{u}}\cap\Omega_{\mathbf{v}}$ is the intersection of the sets of known points in the DSMs. Justification: RPCs can be modeled as affine cameras for small areas of interest (AOIs), e.g. $2 \text{ km} \times 2 \text{ km}$ [3].

② Bundle block adjustment: Detect inter-image tie-points and use prior BA to minimize

$$E(\{T_m\}, \{X_k\}) = \sum_{k} \sum_{m} ||T_m(P_m(X_k)) - x_{mk}||^2,$$
 (2)

where $\{T_m\}$ is a set of correction offsets (1 per image), $\{P_m\}$ are the original RPC projection mappings and $\{X_k\}$ are the 3D points that project on the tie-points $\{x_{mk}\}$.

Justification: RPCs inaccuracies reduce to a 2D translation for AOIs smaller than 50 km \times 50 km [1, 2].

BA of camera rotations: Detect inter-image tie-points and use prior BA to minimize

$$E(\{R_m\},\{X_k\}) = \sum_{k} \sum_{m} \|P_m(R_m(X_k)) - x_{mk}\|^2,$$
 (3)

where $\{R_m\}$ is a set of correcting rotation matrices (1 per image) and the rest is as in (2). Justification: RPCs inaccuracies are due to errors in measurement of satellite attitude (i.e. pointing error).

MVS pipeline

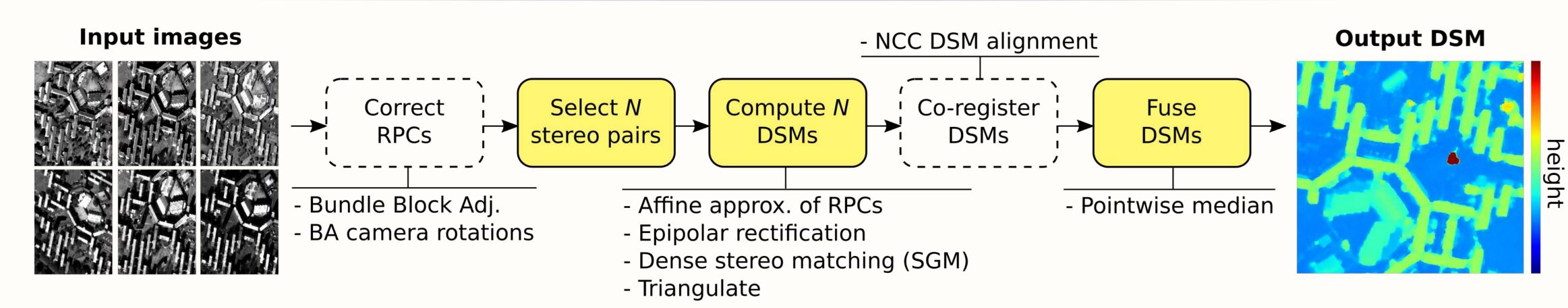


Figure 1: MVS pipeline as used in the experiments. For a fair comparison, yellow blocks are common. Dashed blocks change depending on the relative geolocation correction method employed in each case.

Selection of input pairs

- Oracle order: Sorts stereo pairs by decreasing completeness of the output DSM. Guarantees that the best pairs are selected, but it is expensive to compute and requires availability of ground-truth.
- Heuristic order: Tries to emulate the oracle order based on the satellite images metadata, e.g. intersection angle, incidence angle and proximity of acquisition date [3].
- SIFT order: Sorts stereo pairs in decreasing number of SIFT matches, therefore prioritizing pairs with a higher overlap of visual content.

Data and experiments

- IARPA Multi-View Stereo 3D Mapping Challenge 2016: 47 DigitalGlobe WorldView-3 images, with 30 cm nadir resolution, collected between 2014 and 2016 over Buenos Aires [4].
- IEEE GRSS Data Fusion Contest 2019: 26 DigitalGlobe WorldView-3 images collected between 2014 and 2016 over Jacksonville [5].
- Evaluation metrics: completeness (% of points where error w.r.t ground-truth is smaller than 1 m) and accuracy (root mean squared error). Points in water bodies not taken into account.









Figure 2: The selected AOIs projected on Google Maps.

	IARPA	JAX 113	JAX 161	JAX 251
Oracle order				
NCC DSM alignment	70.62 / 2.67			
Bundle block adjustment - naif	64.39 / 2.72	_	_	_
Bundle block adjustment	70.63 / 2.74	_		
BA of camera rotations - naif	64.50 / 2.71	_	_	_
BA of camera rotations	70.71 / 2.74	_	_	_
Heuristic order				
NCC DSM alignment	68.08 / 2.69	77.72 / 2.00	82.75 / 1.70	74.87 / 2.90
Bundle block adjustment	69.73 / 2.74	77.74 / 2.04	82.53 / 1.73	76.86 / 2.91
BA of camera rotations	69.89 / 2.75	77.72 / 2.04	82.60 / 1.72	75.91 / 2.91
SIFT order				
NCC DSM alignment	48.84 / 2.62	76.73 / 2.01	82.64 / 1.64	72.46 / 2.74
Bundle block adjustment	42.15 / 2.71	76.83 / 2.06	82.48 / 1.66	72.69 / 2.76
BA of camera rotations	42.15 / 2.71	76.79 / 2.04	82.44 / 1.66	71.14 / 2.78

Table 1: Completeness (%) / Accuracy (m) of the reconstructed DSMs for Buenos Aires (1 AOI) and Jacksonville (3 AOIs). The naif label indicates that outliers in the feature tracks for BA were not processed. [5] Bosch, Marc et al., "Semantic stereo for incidental satellite images.". IEEE WACV, 2019.

Results

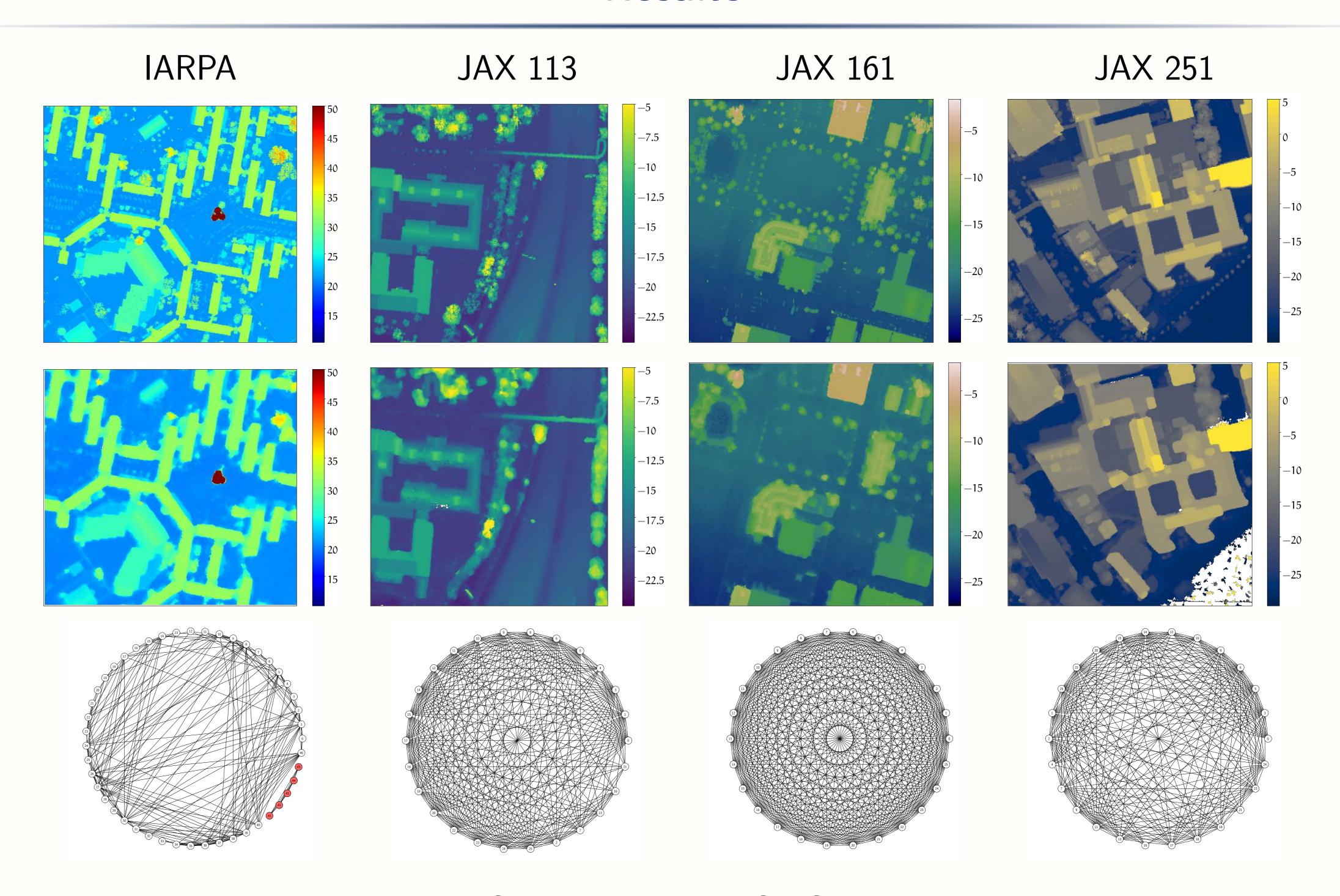


Figure 3: 1st row: Lidar ground-truth DSMs. 2rd row: MVS DSM reconstruction, where white points are unknown. 3rd row: Connectivity graph, where edges link pairs with more than 40 SIFT matches.

Conclusions and discussion

- Image based correction. Methods relying on BA require handling mismatches in feature tracks. If tracks do not connect all images consistently, avoid stereo pairs from disconnected sets (Fig. 3).
- Geometry based correction. NCC DSM alignment is sensitive to incomplete geometry, especially if missing parts are relevant w.r.t. the AOI size. Possible causes: occlusions or water bodies.
- The connectivity graph of pairwise matches could be a useful complement to the heuristic order, because it is adapted to the specific AOI and not to the entire satellite image.
- Image and geometry based correction approaches could be combined to gain robustness.

References

- [1] Grodecki, Jacek and Dial, Gene, "Block adjustment of high-resolution satellite images described by rational polynomials.". PE&RS, 2003.
- [2] Ozcanli, Ozge C. et al., "Automatic geo-location correction of satellite imagery.". IEEE CVPR Workshop, 2014.
- [3] Facciolo, Gabriele et al., "Automatic 3D reconstruction from multi-date satellite images.". IEEE CVPR Workshop, 2017.
- [4] Bosch, Marc et al., "A multiple view stereo benchmark for satellite imagery.". IEEE AIPR Workshop, 2016.