L1B+: A Perfect Sensor Localization Model for Simple Satellite Stereo Reconstruction From Push-frame Image Strips

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Contributions

- A generic method capable of assembling the frames and camera models of a push-frame strip, containing N partially overlapping satellite images.
- Simplify/improve stereo reconstruction from push-frame image acquisitions. Tested on SkySat L1B images.

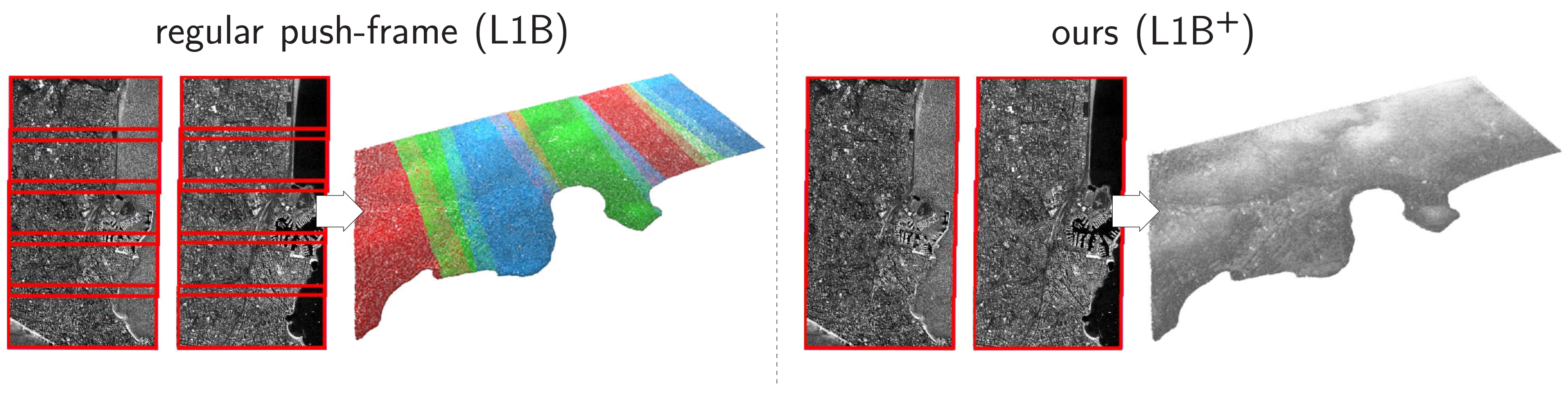

Figure 1: Large scale stereo reconstruction from push-frame acquisitions is a multi-pair problem. Our method simplifies it into a single pair problem.

Methodology Overview

The presented methodology consists of three main steps. We assume that the input images are radiometrically calibrated and cloud free.

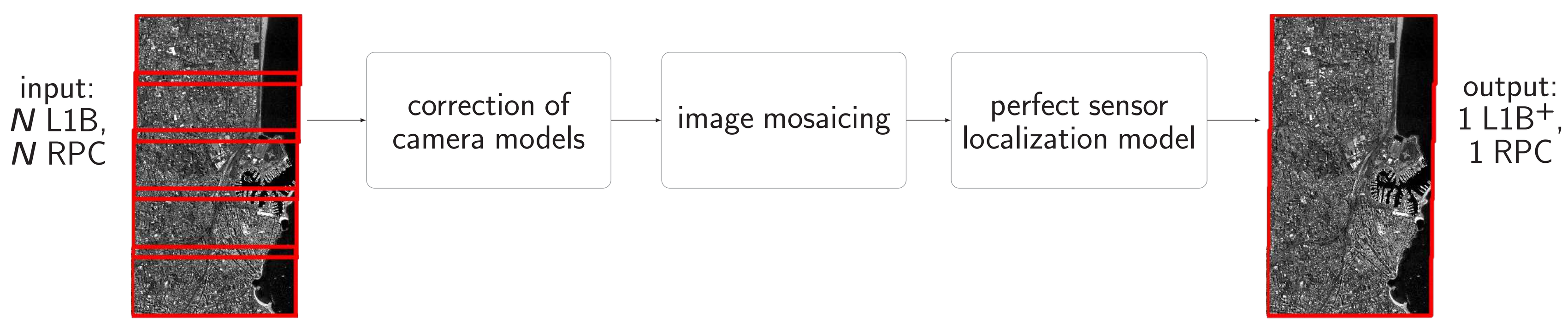

Figure 2: Diagram of the presented methodology.

Step 1 - Correction of Camera Models

Each input L1B image has an associated RPC camera model, which is characterized by a projection function $\mathcal{P}$ and a localization function $\mathcal{L}$.

$$\mathcal{P} : (lon, lat, alt) \longmapsto (col, row)$$
$$\mathcal{L} : (col, row, alt) \longmapsto (lon, lat, alt)$$

Due to the complexity of the system they encode, RPCs usually contain small inaccuracies. We use a **bundle adjustment refinement [1]** to ensure that the RPCs of all the L1B images are geometrically consistent. A 3D point observed by multiple cameras has to project to corresponding 2D locations in the image planes. centreborelli/sat-bundleadjust

Warning: The baseline between L1B images of the same push-frame strip is too small. We use a secondary strip observing the same area to run [1].

Step 2 - Image Mosaicing

Each input image is warped into a common image space using a projective transform H. The H of the central frame of the strip is the identity.

a) Use $\mathcal{L}_i$ and $\mathcal{P}_{i+1}$ to initialize H_i, corresponding to the i-th L1B image.
b) Refine H_i using the Inverse Compositional Algorithm [2].
c) Warp the N L1B images.
d) Average overlapping pixel values.

Warning: Parallax effect is not handled. For SkySat L1B, objects taller than 200m may induce misalignments of $\geq$1 pixel in the mosaic image.

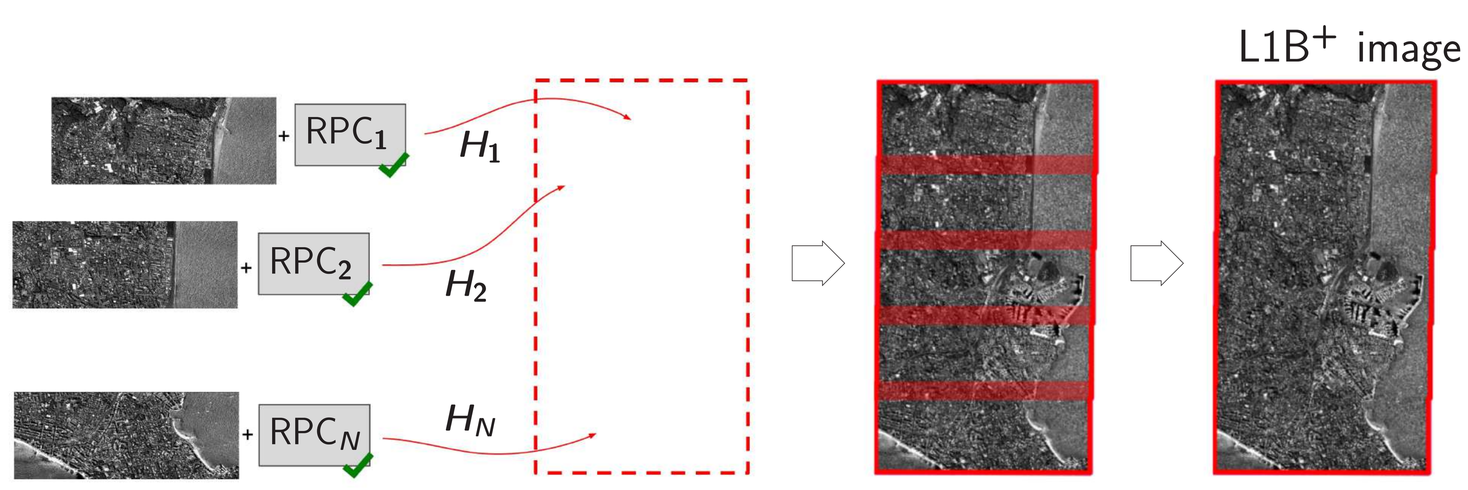

Figure 3: Diagram of the image mosaicing step.

Step 3 - Perfect Sensor Localization Model

We generate a unique RPC camera model that characterizes the entire mosaic image as if obtained by a standard perfect push-broom sensor.

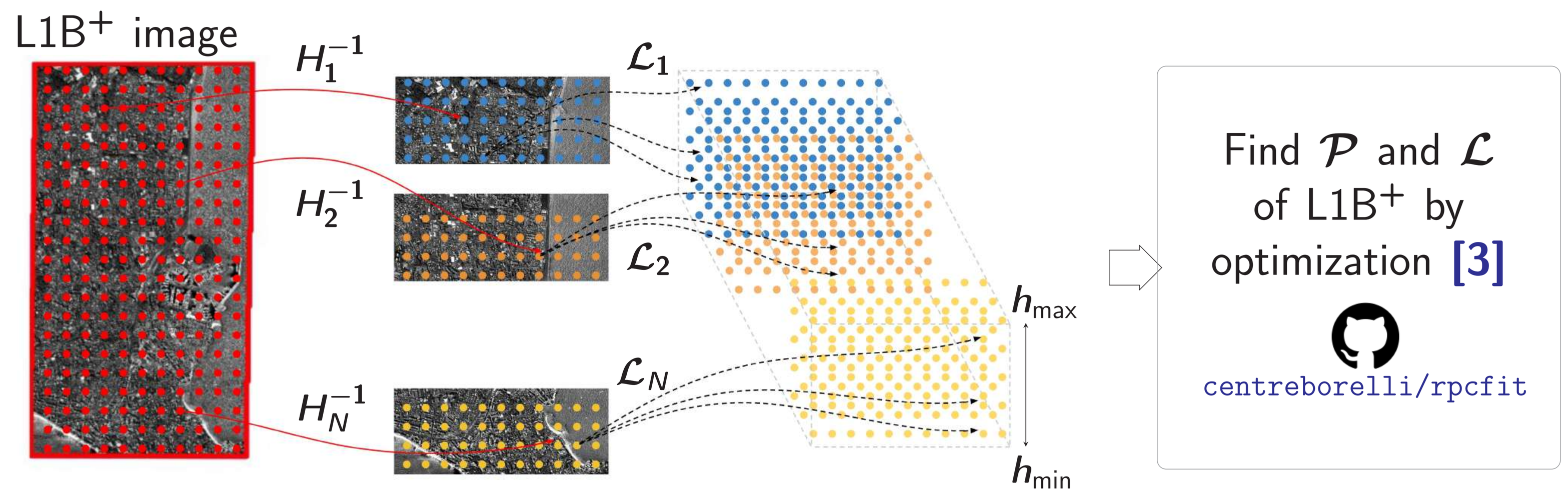

Figure 4: The RPC functions of the L1B+ image are found using a set of correspondences between 2D and 3D points at different altitudes of the scene.

Application to Stereo Reconstruction

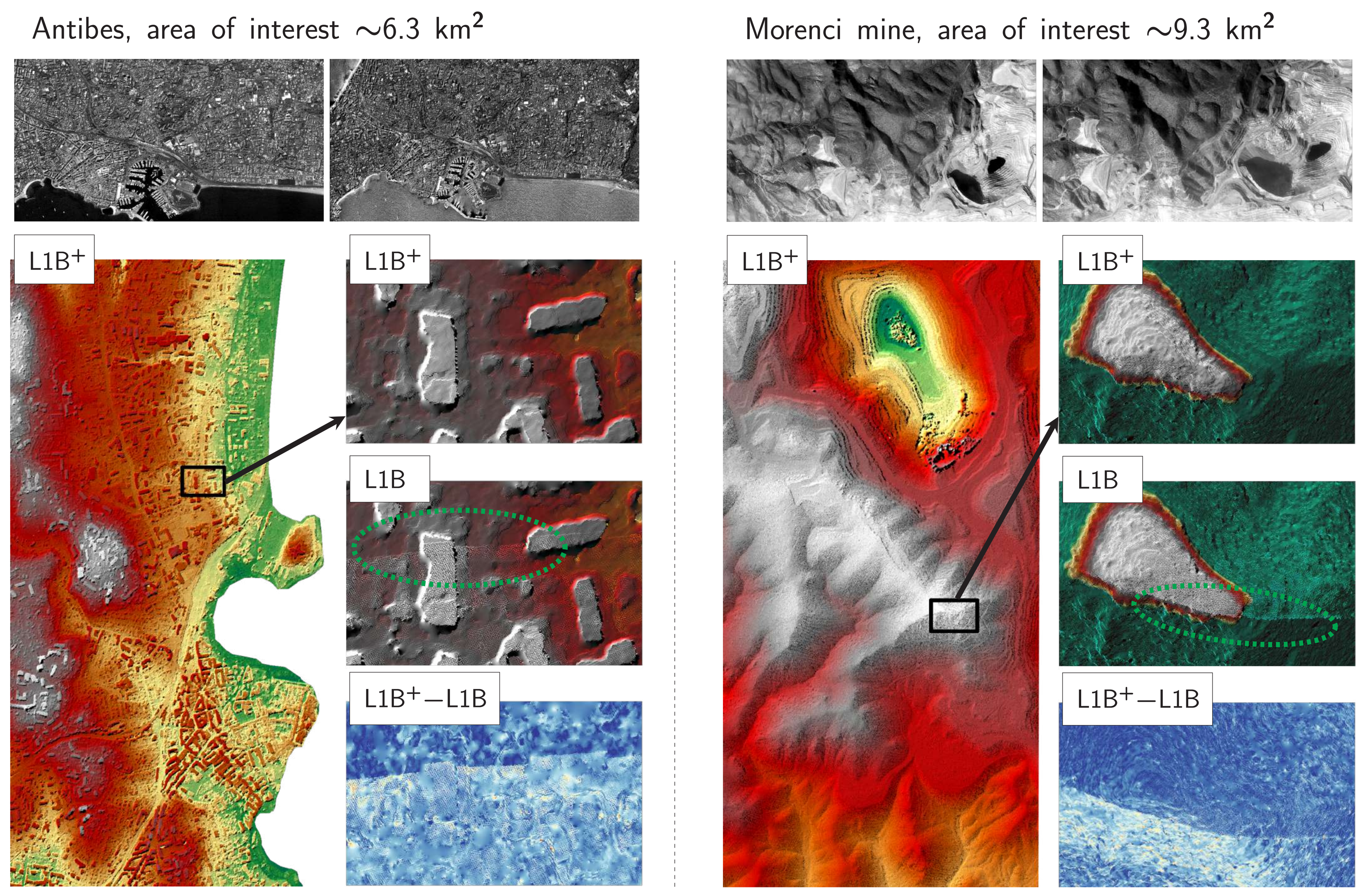

Figure 5: Detailed view of the L1B+ surface models (DSMs) and a subregion of interest. The inspection of the subregions shows that, in absence of outliers, the largest differences between L1B+ and L1B DSMs coincide with small altitude discontinuities (circled in green) in the L1B model.

In our experiments, we feed the satellite stereo pipeline S2P [4] with L1B and L1B+ images

centreborelli/s2p

Data description		MAE [m]		
SkySat strip IDs	N	L1B+-L1B	L1B+-GT	L1B-GT
s107_20210705T131230Z s107_20210705T131300Z (Antibes)	3	0.325	1.214	1.270
	5	0.331	1.204	1.248
s4_20190127T175119Z s4_20190127T175154Z (Morenci)	3	0.391	0.781	0.854
	5	0.395	0.745	0.780

Table 1: Quantitative results of the stereo reconstruction, using 3 or 5 images from the input strips. Left to right: MAE, in meters, between the L1B+ and L1B derived DSMs, and MAE of each DSM with respect to a GT lidar model.

Conclusion

- The L1B+ product is more suitable for large scale applications than the original L1B. E.g. Stereo reconstruction is faster and more accurate.
- Future work: Assemble multiple push-frame strips and not only one.

References

[1] Marí, Roger et al. A generic bundle adjustment methodology for indirect RPC model refinement of satellite imagery. *IPOL*, 2021. doi.org/10.5201/ipol.2021.352

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[4] De Franchis, Carlo et al. An automatic and modular stereo pipeline for pushbroom images. *ISPRS Annals*, 2014. doi.org/10.5194/isprsannals-II-3-49-2014