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Project acronym: LADIO Project number: 731970 Work package: Deliverable number and name: D3.5: Lens calibration from 3D Reconstruction in openMVG	Title: Lens calibration from 3D Reconstruction in openMVG Work Package: WP3 Version: 1 Date: April 10, 2017 Author: Tomas Pajdla
Type: [ ] Report [ ] Demonstrator, pilot, prototype [ ] Website, patent filings, videos, etc. [X] Other	Co-Author(s): Fabien Castan To: Albert Gauthier, Project Officer
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Revision: Final	
Contents: Deliverable 3.5. Implement lens calibration from 3D Reconstruction in openMVG.	

Resectioning

The AliceVision[1] photogrammetry pipeline requires an initial estimate of the **focal length** to perform the resectioning. For DSLR cameras we use the focal length information in millimeters from the EXIF. We use a database with sensor width information to convert it in pixels.
There are 2 failure cases:

- No EXIF information available
- Unknown camera model in the database

Then on a shooting set, we also need to get this information from the Live Action video stream to perform the camera localization. We can receive this information through SDI metadata, but it's only supported by few cameras. So it is also an issue in the context of Previz to provide real-time camera localization.

Another limitation in the AliceVision photogrammetry pipeline is the robustness to radial distortion. The resectioning step ignores the radial distortion and relies on the Bundle Adjustment to refine this value. But if the distortion is important, the resectioning will fail or reject many valid features.

This task solves all these issues by providing new solvers that can deal with different configurations.

Unknown focal length and ignoring radial distortion

We have used our previous result [1] to generate a solution to camera absolute pose with unknown focal length. The solver [1] solves for camera pose C, rotation R and focal length f from four 3D-2D matches.

Figure 1 shows ten projections of 3D points of the "Buddha" scene Figure 2(a), into images. The 3D points are shown in blue color. Inliers to the camera absolute pose with unknown focal length [1], which were obtained by RANSAC [3] with 500 samples and maximal error equal 2 pixels, are shown in green. We see that large majority of points were fit by the model.

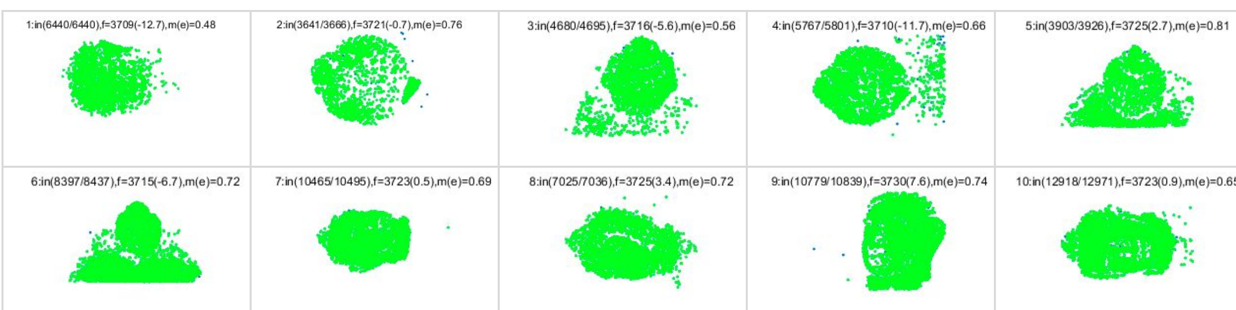

Figure 1. First ten image projections of the "Buddha" scene (blue) with inliers (green) to absolute pose with unknown focal length model fitting.

[1] AliceVision is the new global Github repository that hosts all LADIO project's pieces of software. More generally AliceVision hosts all the collaborative projects' softwares regarding 3D reconstruction and camera tracking, that have been initiated by H2020 POPART and LADIO partners. Most of these software are open source, unless they are still under initial development.
https://github.com/alicevision

Figure 2(b) illustrates the result of the fitting. The green curve shows the inlier ratio, i.e. the ratio of the number of inliers to the number of all tentative matches. We see that it is always very close to one. Estimated focal lengths were compared to the “ground truth” focal lengths obtained by a full bundle adjustment optimization. The blue curve shows the ratio of the estimated focal lengths to the ground truth focal lengths. We see that it is also always very close to one. The red curve shows the mean reprojection error for all inliers. We see that the error is below a single pixel. It is a very good result, since the model was computed from four points only and no additional optimization considering all inliers has been used.

Table 1. “Buddha” scene: Numerical results of the focal length estimation as well as inlier ratios for the computation of absolute pose with unknown focal length.

Estimated f [pixels]	3709	3721	3716	3710	3724	3715	3722	3725	3729	3723
True f [pixels]	3722	3722	3722	3722	3722	3722	3722	3722	3722	3722
Inlier ratio [%]	100	99.3	99.7	99.4	99.4	99.5	99.7	99.8	99.5	99.6

Table 1 shows the numerical results of the focal length estimation as well as inlier ratios for the computation of absolute pose with unknown focal length.

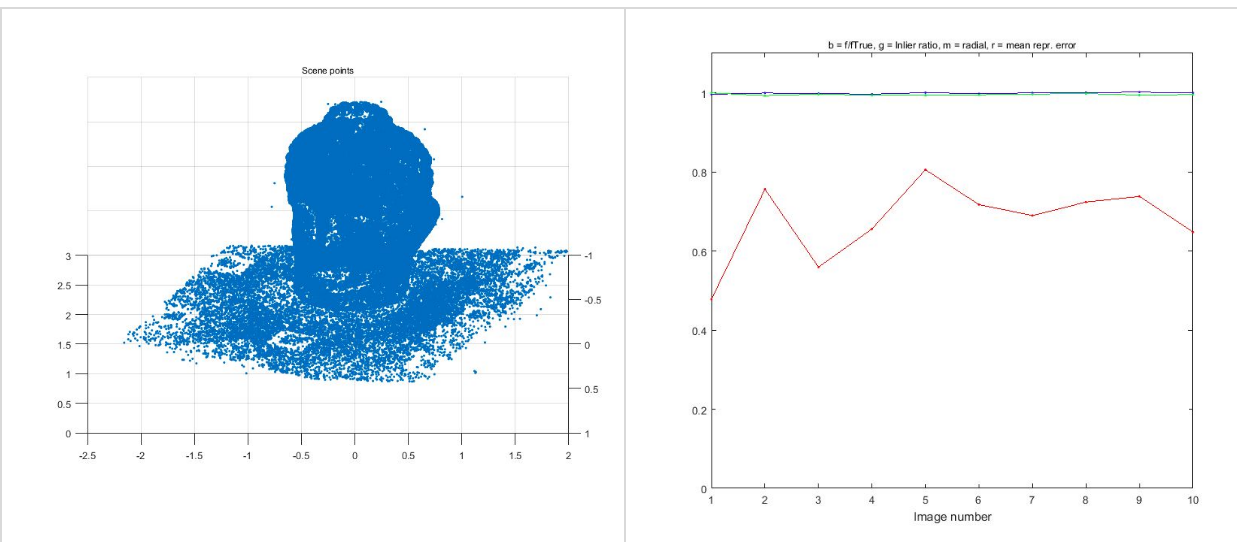

Figure 2. (a) “Buddha” scene and (b) the comparison of the estimated focal length to the “ground truth” focal length (blue), inlier ratio (green) and mean reprojection error (red).

We can conclude that the solver [1] of the absolute pose with unknown focal length delivers accurate results for real images when used in RANSAC.

Unknown focal length and unknown radial distortion

We have used our previous result [2] to generate a solution to camera absolute pose with unknown focal length and unknown radial distortion. The solver [2] solves for camera pose C, rotation R and focal length f and 1-3 coefficients of the radial un-distortion division model from five 3D-2D matches.

Figure 4 presents similar results as Figure 2. It is interesting to note two things. First, the mean reprojection error, albeit still low, has increased. This is expected since we are now using a model with more parameters that is harder to fit to extrapolate on unseen data. The error is still below or very slightly above one pixel. Secondly, the magenta curve shows that the estimated radial distortion coefficients is very close to zero. This is expected since images do not exhibit any large radial distortion. Table 2 shows the corresponding numerical results. We can conclude that the solver [2] is stable even for the case when there actually is no radial distortion. Still, it is slightly less favourable compared to solver [1] in such case since it (1) calls for five instead of four points and (2) has slightly lower prediction capacity than [1].

Table 2. "Buddha" scene: Numerical results of the focal length and radial distortion estimation as well as inlier ratios for the computation of absolute pose with unknown focal length and unknown radial distortion.

Estimated f [pixels]	3715	3726	3710	3709	3724	3708	3729	3716	3717	3726
True f [pixels]	3722	3722	3722	3722	3722	3722	3722	3722	3722	3722
Inlier ratio [%]	100	99.3	99.1	99.2	99.4	99.6	99.7	99.8	99.4	99.5

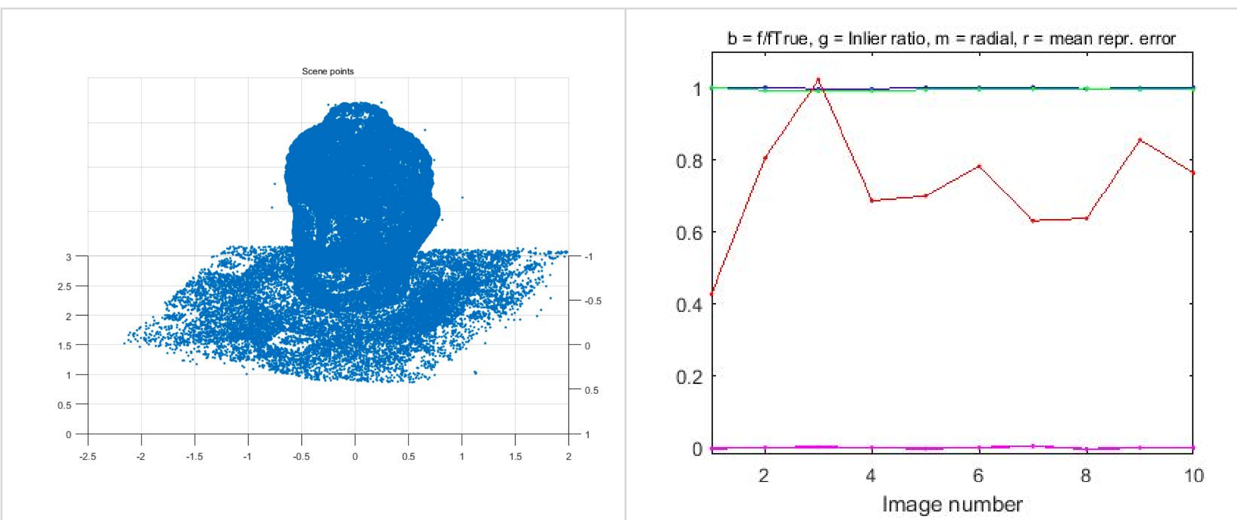

Figure 4. (a) "Buddha" scene and (b) the comparison of the estimated focal length to the "ground truth" focal length (blue), inlier ratio (green), mean reprojection error (red) and estimated single-parameter division radial distortion coefficient (magenta).

Figure 5 shows ten projections of 3D points of the "Street" scene Figure 6(a), into images. Some images of the "Street" scene exhibit large radial distortion since they were acquired by Go-Pro cameras. Other images may have much smaller radial distortion because they were acquired by a camera with narrow field of view, and hence also long focal length. Projections of the 3D points are shown in blue color. Inliers to the camera absolute pose with unknown focal length [1], which were obtained by RANSAC [3] with 500 samples and maximal error equal 2 pixels, are shown in green. We see that the model that neglects radial distortion can't really fit data well. Inlier ratios are small, often much below 50%, reprojection errors get close to the threshold 2 pixels. It is interesting to note that focal lengths are often not estimated too badly and most of the inliers are close to the center of the image, where the optical distortion has less impact. Many are similar to the true focal length but there are also very different ones. We can conclude that the “Street” data set indeed calls for the ability to model radial distortion.

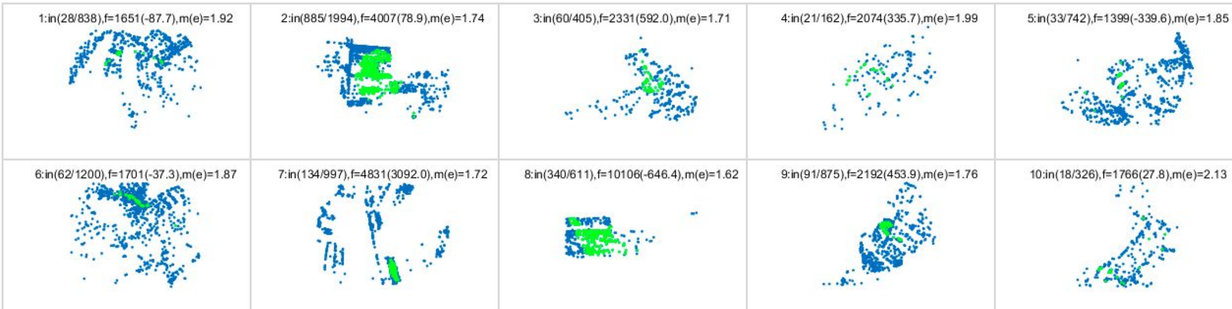

Figure 5. First ten image projections of the “Street” scene (blue) with inliers (green) to absolute pose with unknown focal length model fitting.

Table 3 shows the numerical results of the focal length estimation as well as inlier ratios for the computation of absolute pose with unknown focal length on the “Street” scene. We see that inlier ratios are very small and some focal lengths are estimated far from the ground truth.

Table 3. “Street” scene: Numerical results of the focal length estimation as well as inlier ratios for the computation of absolute pose with unknown focal length.

Estimated f [pixels]	3630	3935	2026	2095	1972	1410	2831	1015	1730	1828
True f [pixels]	1739	3928	1739	1739	1739	1739	1739	1075	1739	1739
Inlier ratio [%]	3.1	46.7	17.8	14.8	7.3	6.5	10.6	54.9	9.4	4.9

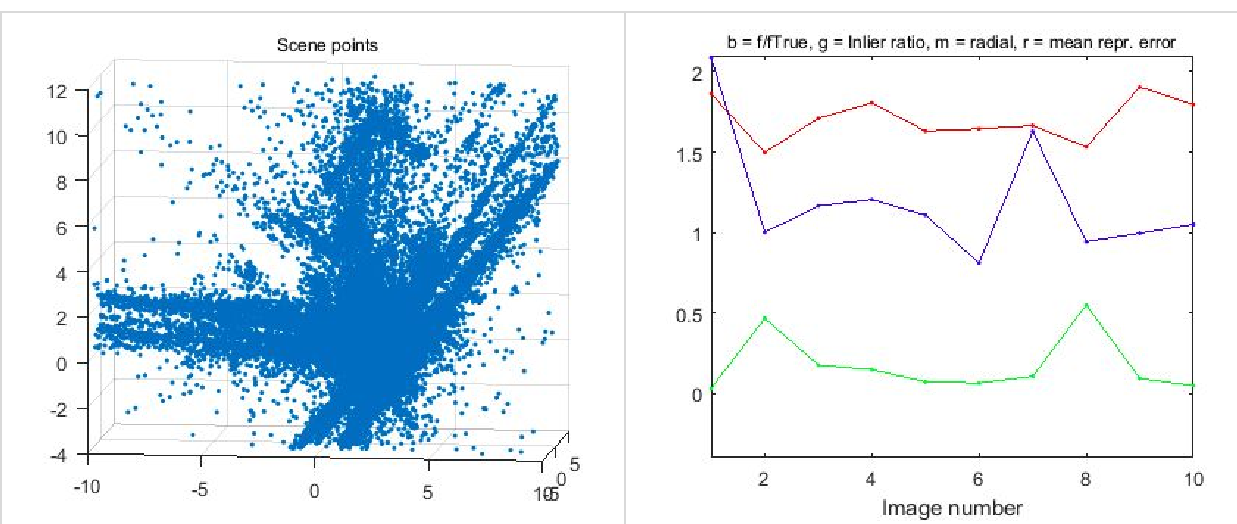

Figure 6. (a) “Street” scene and (b) the comparison of the estimated focal length to the “ground

truth” focal length (blue), inlier ratio (green), mean reprojection error (red) for absolute pose with unknown focal length.

Figure 7 shows ten projections of 3D points of the “Street” scene Figure 7(a), into images. Projections of the 3D points are shown in blue color. Inliers to the camera absolute pose with unknown focal length and single-parameter division radial undistortion model [2], which were obtained by RANSAC [3] with 500 samples and maximal error equal 2 pixels, are shown in green. We wee that the model fits data well. Inlier ratios are large, Table 4, often above 75%, reprojection errors still smaller than the threshold 2 pixels. We can conclude that we estimate the focal laength accurately and are able to explain majority of image measurements.

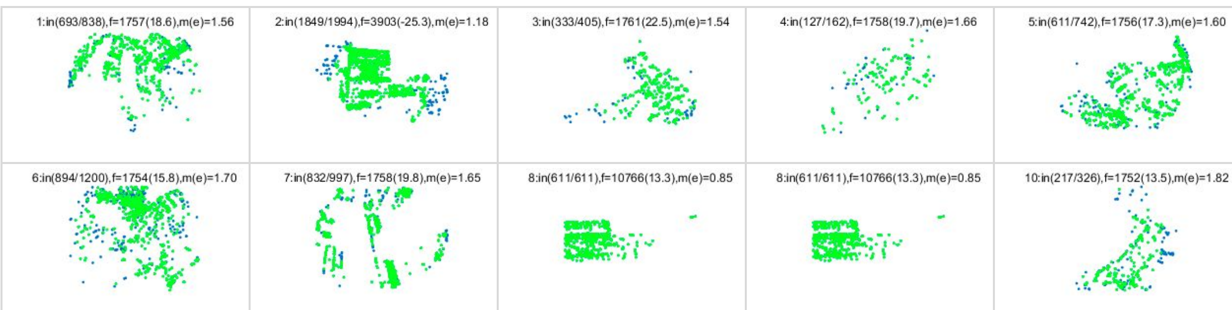

Figure 7. First ten image projections of the “Street” scene (blue) with inliers (green) to absolute pose with unknown focal length and unknown radial division model fitting.

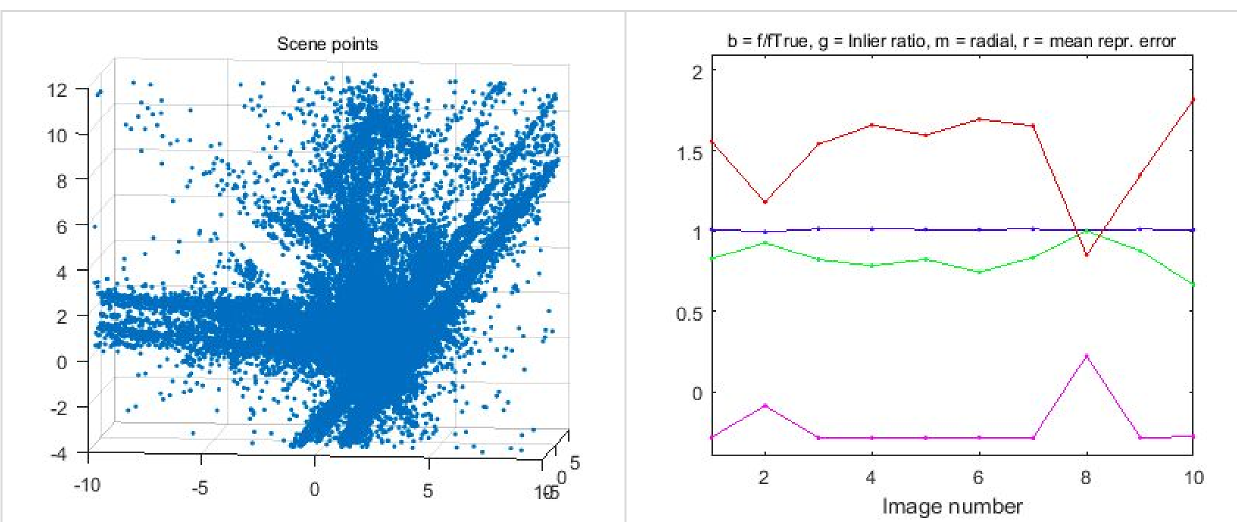

Figure 8. (a) “Street” scene and (b) the comparison of the estimated focal length to the “ground truth” focal length (blue), inlier ratio (green), mean reprojection error (red) and estimated single-parameter division radial distortion coefficient (magenta).

Table 4. "Street" scene: Numerical results of the focal length estimation as well as inlier ratios for the computation of absolute pose with unknown focal length and unknown single-parameter .

Estimated f [pixels]	1757	3903	1761	1758	1756	1754	1758	1076	1758	1752
True f [pixels]	1739	3928	1739	1739	1739	1739	1739	1075	1739	1739
Inlier ratio [%]	82.7	92.7	82.2	78.4	82.4	74.5	83.5	100	87.8	66.5

Distortion model conversion

Radial distortion computation by solver [2] is based on the single-parameter division radial undistortion model [2, Eqn. 4]. To be able to initialize non-linear bundle adjustment optimization, which needs a distortion model, it is necessary to convert the un-distortion model into a distortion one. In general, there is no closed-form solution for inverting undistortion models into the distortion ones, i.e. inverting a function. There is a closed form formula for inverting the single-parameter division undistortion model but for division undistortion models with more parameters, only approximate inversion is possible in general.

To facilitate standard bundle adjustment in OpenMVG, we have implemented a method for converting the inversion of the division un-distortion model into a standard Brown polynomial distortion model [3]. We base our approach on the least squares approximation.

Let r be undistorted and d distorted radii, respectively. The division undistortion model reads as

$$r = f(d,k) = d/(1 + k1*d^2 + k2*d^4 + k3*d^6)$$

We want to approximate the inverse of f by a polynomial distortion model

$$d = g(r,p) = r*(1 + p1*r^2 + p2*r^4 + p3*r^6)$$

on points $d_i \in$ interval [0 D], for i = 1, ..., n by solving the optimization problem

$$p^* = \mathrm{argmin}_p \sum_i (d - g(f(d,k),p))^2$$

This leads to a linear system A p = b on unknown coefficients p = [p1, p2, p3], which is easy to solve. Figure 9 shows an example of finding the inversion of the division model with parameters k1 = -1e-1, k2 = -5e-2, k3 = -5e-2. We see that the approximation error does not exceed 3/10000 of the range of the mapping.

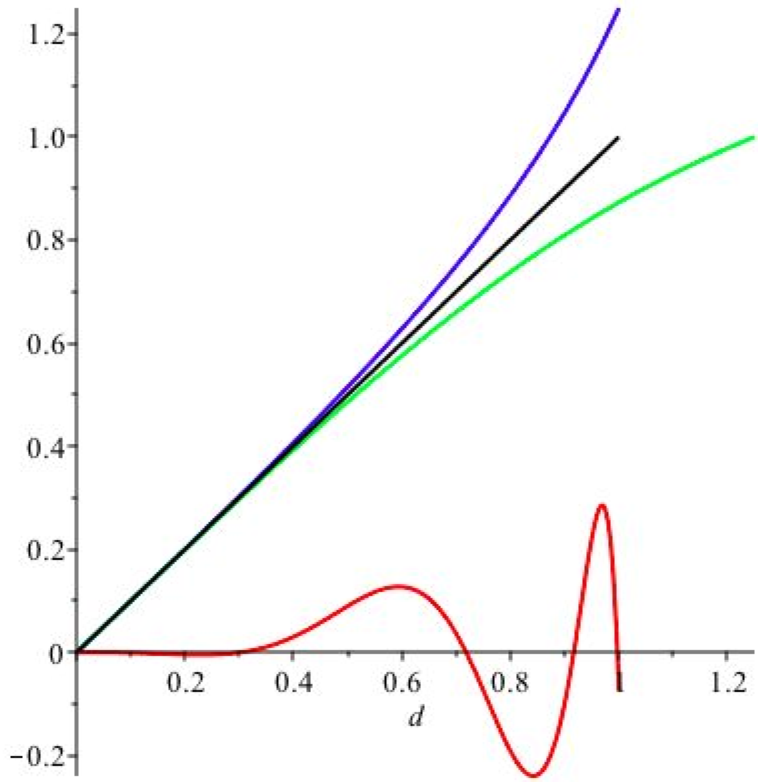

Figure 9. Approximation of the inversion of radial division un-distortion model by Brown polynomial distortion mode. Un-distorted radius is on the horizontal axis. Distorted radius is on the vertical axis. Division un-distortion mapping is shown in blue. Its inversion approximated by Brown polynomial distortion model is shown in green. The composition of the two is shown in black. The approximation error, i.e. the difference between the black curve and the identity mapping, multiplied by 1000 is shown in red.

Conclusion

The Matlab code for the 2 resectioning methods and the Maple code for distortion model conversion is uploaded on gitlab: https://gitlab.com/alicevision/pnpMinimalSolvers
We are now integrating these new PnP solvers in openMVG. This will enable to support images without metadata in the SfM pipeline. Then we will integrate it in the offline camera tracking and in the previz tool.

In the future, we would like to investigate the resectioning when we have an initial knowledge of the focal length but we need to estimate the radial distortion to support images with large distortion (like fisheye optics). There is no such minimal solver in the literature for this particular use case.

References

[1] *M. Bujnak, Z. Kukelova, T. Pajdla. A general solution to the P4P problem for camera with unknown focal length. CVPR 2008* (http://cmp.felk.cvut.cz/~bujnam1/publications/Bujnak-et-al-CVPR-2008-final.pdf).

[2] Z. Kukelova, M. Bujnak, T. Pajdla. Real-time solution to the absolute pose problem with unknown radial distortion and focal length. ICCV 2013, (http://cmp.felk.cvut.cz/~kukelova/publications/Kukelova-Bujnak-ICCV-2013.pdf).

[3] R. Hartley, Z. Zisserman. Multiple View Geometry in Computer Vision. Cambridge Press 2003.