HARD-PnP: Extended results

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1 Extended refinement results

Below we include refinement results from the final experiment in Section 6.2 of [1], but using each of the remaining 8 state-of-the-art techniques.

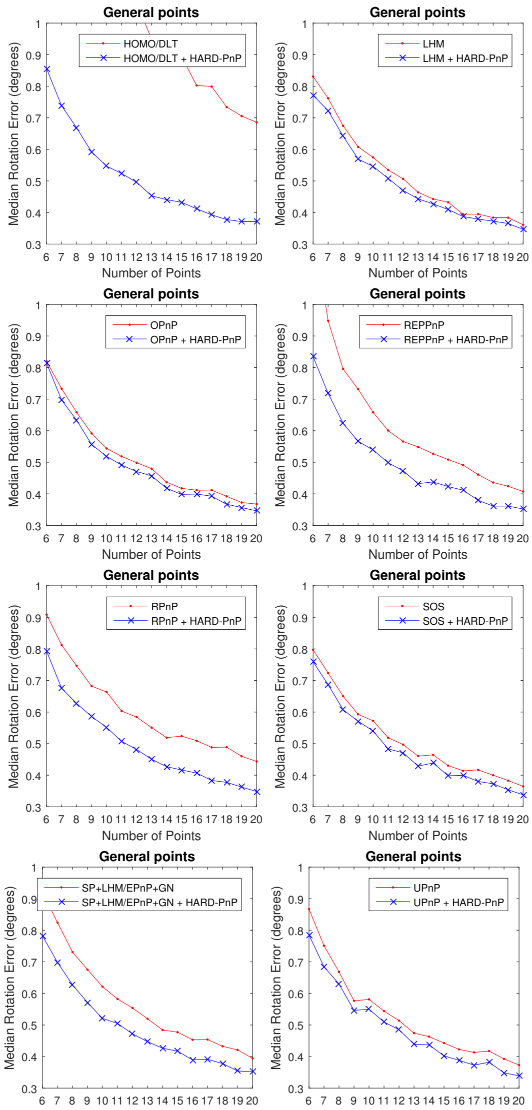

Fig. 1: Using HARD-PnP as an alternative refinement step for existing techniques.

2 Evaluation on real data

Below we apply a range of PnP algorithms to points obtained via SIFT matching on real data, which includes incorrect match outliers and noise in the localization. Figure 2 shows the box vertices transferred from the reference frame using the pose estimated by the different methods. The first and second rows relate to the general configuration "box" data of [2] and [3] respectively. The bottom row is for the planar "bookcover" data [2].

Note that for clarity, we have included only the best performing **HARD-PnP** variant, the baseline **RNSC P3P** and the state of the art **REPPnP** technique. The first scene is the easiest with variations between the techniques of only a few pixels. However, **REPPnP** does estimate the leftmost corner somewhat incorrectly. The second sequence is much higher resolution, and the inadequacy of the baseline technique becomes evident, exhibiting errors of around 30 pixels. The proposed technique performs similar to state-of-the-art in this case. The final planar scene proves to be the most challenging. **REPPnP** fails to estimate a feasible transformation. The remaining techniques exhibit some difficulty placing the topmost corner, however the estimated poses are still quite feasible and the other corners are relatively accurate.

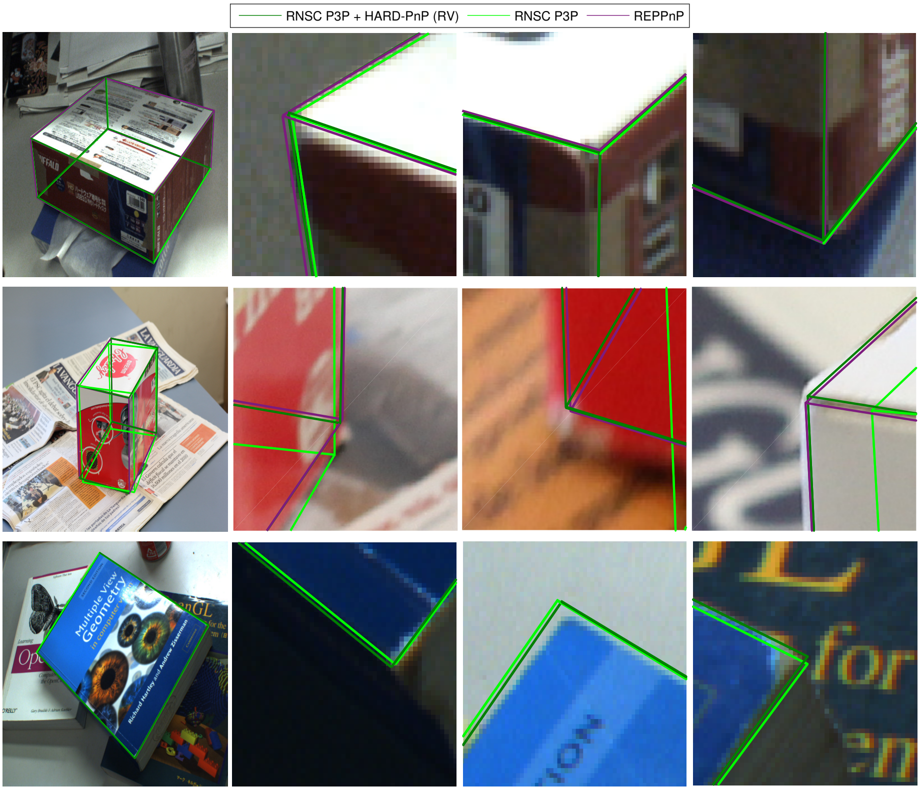

Fig. 2: PnP performance on real matching data for 3 different scenes: top row "box" [2], central row "box" [3] and bottom row "bookcover" [2].

3 Extended evaluation of proposed techniques

For every experiment in Section 6.1 of [1], we here include the additional error measures (translation error and reprojection error).

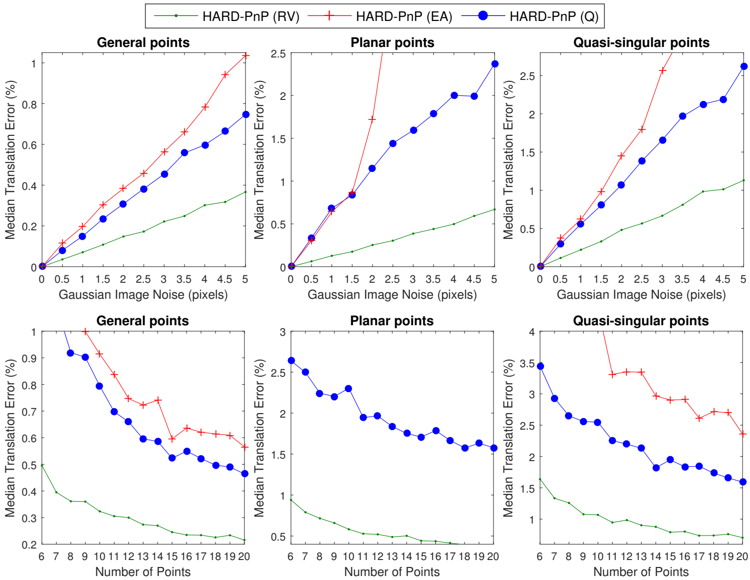

Fig. 3: Comparison of translation error for different variants of HARD-PnP.

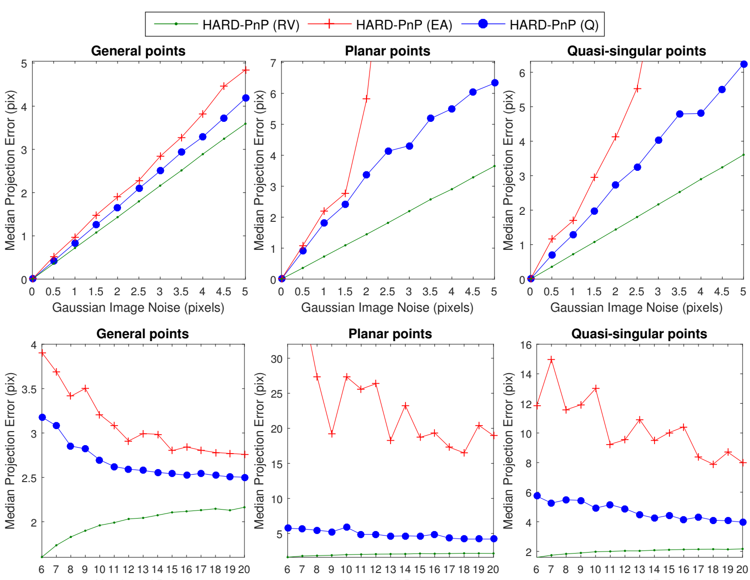

Fig. 4: Comparison of projection error for different variants of HARD-PnP.

4 Extended comparison to State of the Art

For every experiment in Section 6.2 of [1], we here include the additional error measures (translation error and reprojection error). It is interesting to note that the projection error actually rises as the number of points increases (even though the rotation and translation decrease). This is due to "overfitting". It is always possible to achieve 0 projection error for any 3 points, however as more points are added the pose is forced to make more and more of a tradeoff between the points, increasing the projection error.

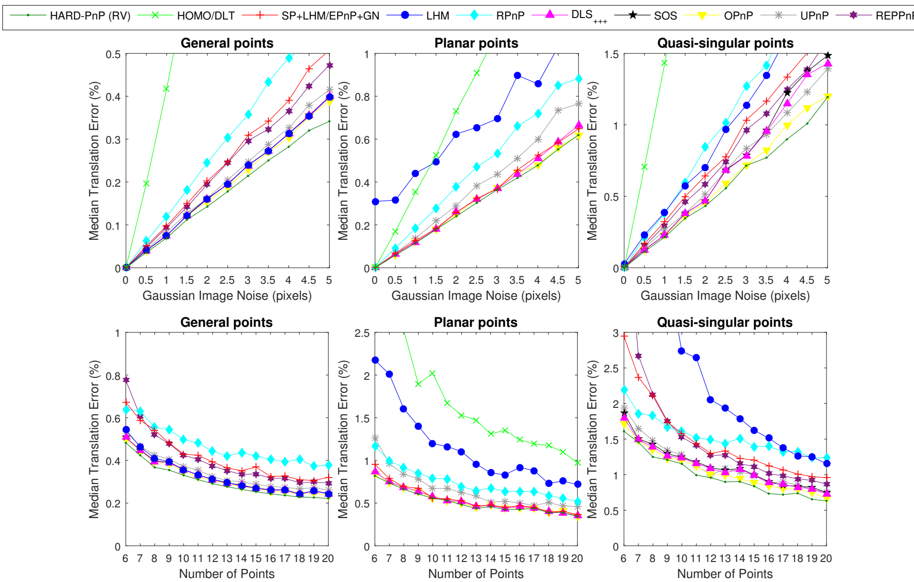

Fig. 5: Comparison of the translation error for the proposed HARD-PnP algorithm against the previous state-of-the-art.

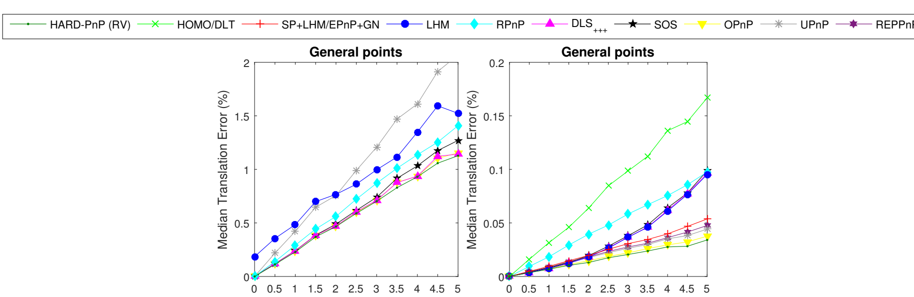

Fig. 6: Left: Evaluation of translation error with only 4 points and varying noise levels. Right: Evaluation of performance with 2000 points at varying noise levels.

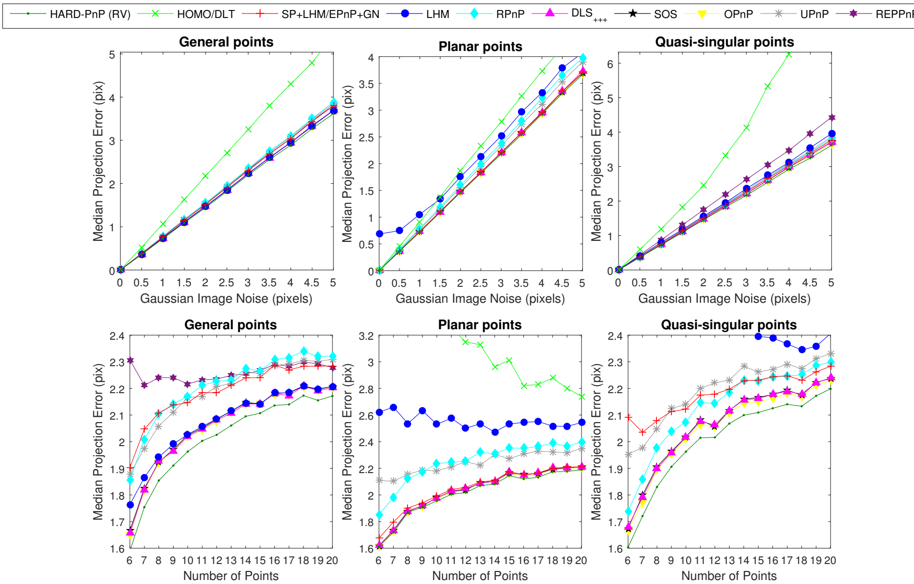

Fig. 7: Comparison of the projection error for the proposed HARD-PnP algorithm against the previous state-of-the-art.

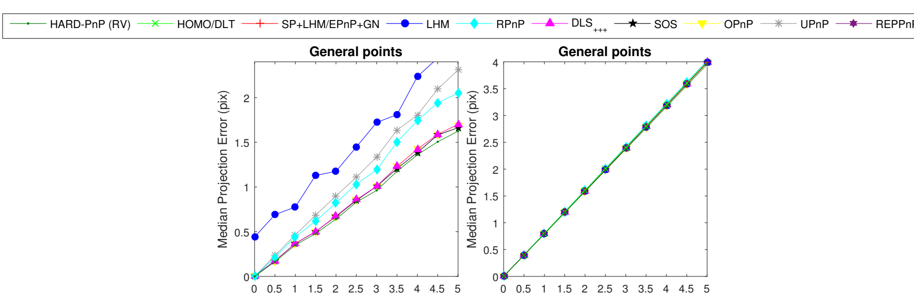

Fig. 8: Left: Evaluation of projection error with only 4 points and varying noise levels. Right: Evaluation of performance with 2000 points at varying noise levels.

5 Extended performance with outliers

For the experiment in Section 6.3 of [1], we here include the additional error measures (translation error and reprojection error).

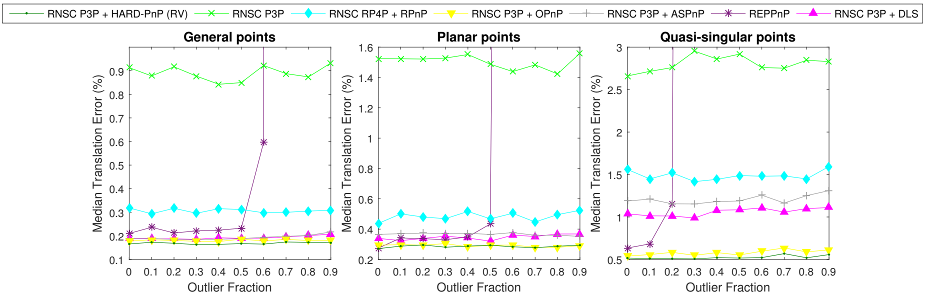

Fig. 9: Comparison of the translation error for the proposed HARD-PnP algorithm against the previous state-of-the-art, with varying numbers of outliers (100 inliers and noise level of 5 pixels). Left to right show performance in the general, planar and quasi-singular configurations respectively.

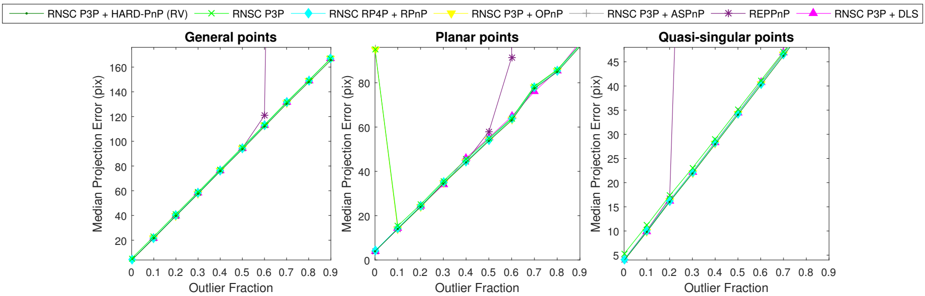

Fig. 10: Comparison of the projection error for the proposed HARD-PnP algorithm against the previous state-of-the-art, with varying numbers of outliers (100 inliers and noise level of 5 pixels).

6 Additional results with outliers

Below we repeat the experiments from Section 6.2 of [1], with the addition of 20 % outlier contamination and using the RANSAC techniques from Section 6.3 of [1]. Note that the periodicity observed in Figure 15 is because every fourth point added is a new outlier (in order to maintain the outlier ratio) and these outliers obviously have high reprojection errors. However, this periodicity does not manifest itself in the pose errors (i.e. new outliers do not have any significant effect on accuracy).

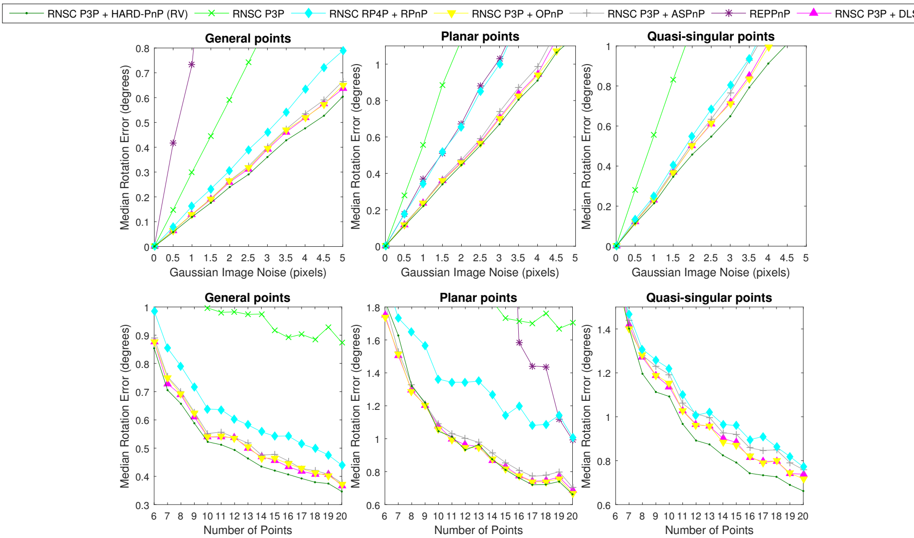

Fig. 11: Comparison of the orientation error for the proposed HARD-PnP algorithm against the previous state-of-the-art, with 20 % outlier contamination.

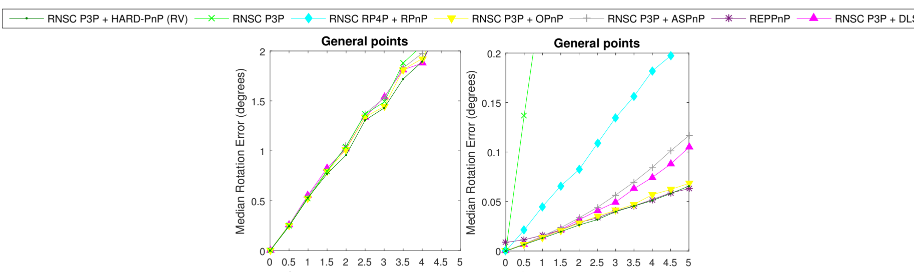

Fig. 12: Left: Evaluation of orientation error with only 4 points and varying noise levels. Right: Evaluation of performance with 2000 points at varying noise levels. Both with 20 % outlier contamination.

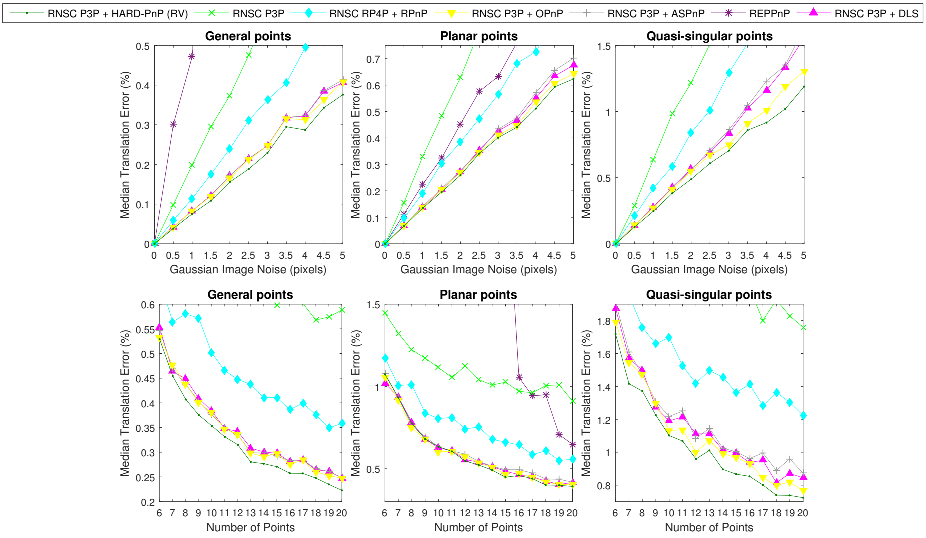

Fig. 13: Comparison of the translation error for the proposed HARD-PnP algorithm against the previous state-of-the-art, with 20 % outlier contamination.

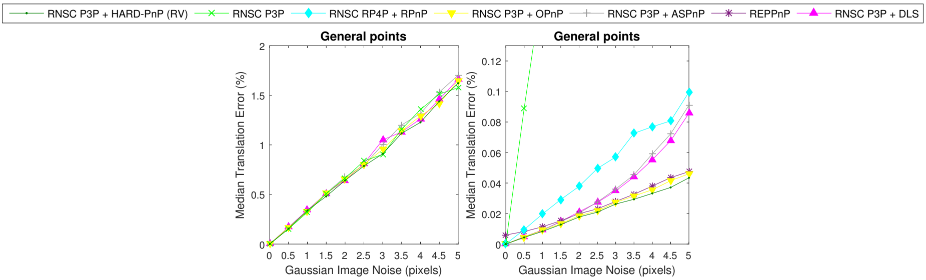

Fig. 14: Left: Evaluation of translation error with only 4 points and varying noise levels. Right: Evaluation of performance with 2000 points at varying noise levels. Both with 20 % outlier contamination.

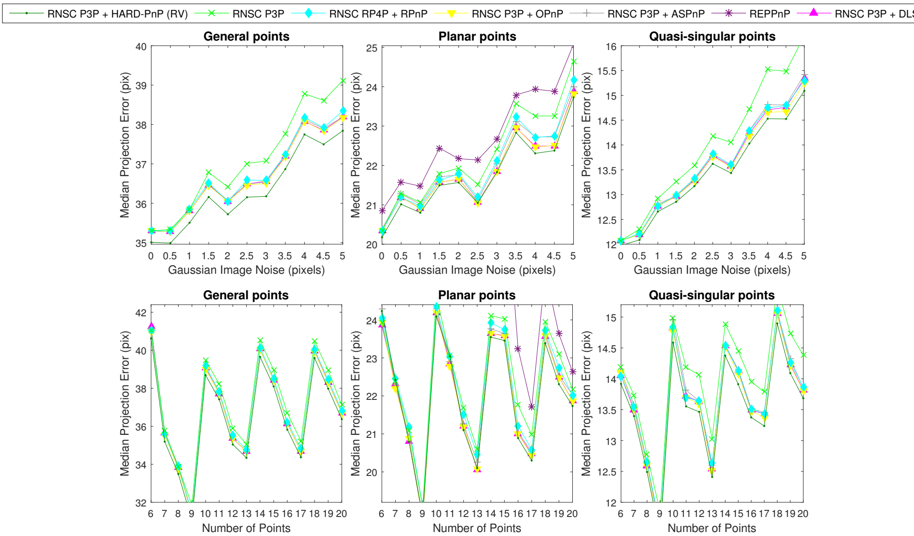

Fig. 15: Comparison of the projection error for the proposed HARD-PnP algorithm against the previous state-of-the-art, with 20 % outlier contamination.

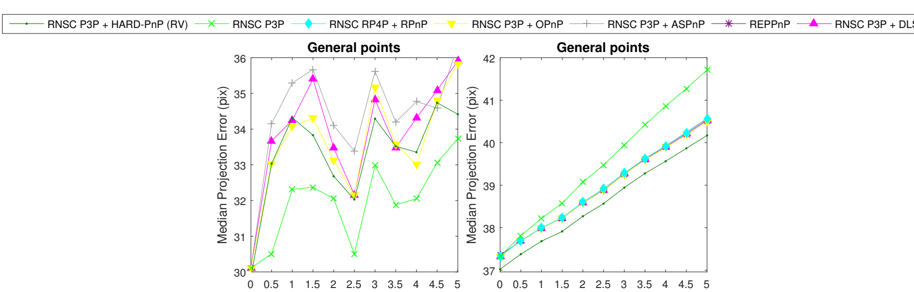

Fig. 16: Left: Evaluation of projection error with only 4 points and varying noise levels. Right: Evaluation of performance with 2000 points at varying noise levels. Both with 20 % outlier contamination.

References

1. Hadfield, S., Lebeda, K., Bowden, R.: HARD-PnP: PnP optimization using a hybrid approximate representation. In: Submitted to TPAMI. (2016) 1, 3, 4, 6, 7
2. Zheng, Y., Kuang, Y., Sugimoto, S., Astrom, K., Okutomi, M.: Revisiting the PnP problem: A fast, general and optimal solution. In: Proc. ICCV, Sydney, Australia, IEEE (December 3 – 6 2013) 2344–2351 2
3. Ferraz, L., Binefa, X., Moreno-Noguer, F.: Very fast solution to the PnP problem with algebraic outlier rejection. In: Proc. CVPR, Columbus, USA (June 24 – 27 2014) 501–508 2