STEREO VISION ACCURACY VERSUS RESIDUAL LENS DISTORTION

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Abstract

This work aims to quantify the effects of residual lens distortion (after camera calibration) on the spatial accuracy of 3D coordinates measured by triangulation with a stereo camera pair. Easily locatable checker references are used to isolate the problem from image segmentation and matching errors. Different orders of Brown's[1, 2] distortion model, with and without asymmetrical radial gains[3], are compared to prevalent calibration methods[4] with a common dataset to yield real-world spatial accuracies.

Numerical Optimisation

- Fit any number of radial and tangential terms plus optimal distortion center.
- 7 Parameters for extrinsic calibration.
- Genetic Algorithm to find starting point.
- Floating point genes, elitism, dominance.
- Leapfrog optimisation - robust, finds "low" minimums.
- Parameters independantly scaled to normalize gradient sensitivity.
- Centered difference calculation for improved gradient estimation.
- After first leapfrog pass, identify and eliminate outliers.
- Repeat Leapfrog optimisation.
- Best fit straight lines for distortion metric fitted with analytic least squares method.

Equipment

- $2\times$ 2MP Prosilica GE1660 cameras.
- Schneider Cinegon 4.8mm lens (monotonic barrel distortion).
- Goyo GMB5HR30528MCN 5.0mm optically corrected lens (moustache distortion).
- 46" HD LCD to disply optical patterns.
- 9×8 checker board with 40mm squares for CalTech calibration.
- Baton with 2 checkers at a constant displacement.

References

[1] D.C. Brown, Decentering distortion of lenses, in *Photogrammetric Engineering*, 1966

[2] D.C. Brown, Close Range Camera Calibration, in *Photogrammetric Engineering*, 1971

[3] J.P. de Villiers, F.W. Leuschner, R. Geldenhuys, Modeling of radial asymmetry in lens distortion facilitated by modern optimization techniques, in *Proceedings of the 2010 Electronic Imaging Conference*, 2010

[4] CalTech Camera Calibration Toolkit `http://www.vision.caltech.edu/bouguetj/calib_doc/`

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Lens Distortion Correction

Brown's Distortion model:

$$x_u = x_d + f(\theta)x_\delta(K_1 r^2 + K_2 r^4 + \ldots) + \left(P_1(r^2 + 2x_\delta^2) + 2P_2 x_\delta y_\delta\right)(1 + P_3 r^2 + \ldots)$$
$$y_u = y_d + f(\theta)y_\delta(K_1 r^2 + K_2 r^4 + \ldots) + \left(2P_1 x_\delta y_\delta + P_2(r^2 + 2y_\delta^2)\right)(1 + P_3 r^2 + \ldots)$$

Distortion metric:

$$distortion = \sqrt{\frac{1}{\sum_{n=0}^{n<N} M_n} \sum_{n=0}^{n<N} \sum_{m=0}^{m<M_n} \left((\|\bar{p_p^n} - \bar{p_l^n}\|_2)^2 - ((\bar{p_p^n} - \bar{p_l^n}) \bullet \bar{d_n})^2 \right)}$$

Extrinsic Calibration

Minimise angular difference between two vector bundles:

$$Metric = \sum_{i=0}^{n-1} \left(cos^{-1}\left(\frac{V_{icc}^1}{\| V_{icc}^1 \|} \bullet \frac{V_{icc}^2}{\| V_{icc}^2 \|} \right) \right)$$

Bundle created from captured image data:

$$I_i^u = f^{undistort}(I_i^d)$$
$$V_{icc}^1 = \begin{bmatrix} Focal\_Len \\ (P_h - I_{i_h}^u) \times pix\_w \\ (P_v - I_{i_v}^u) \times pix\_h \end{bmatrix}$$

Bundle created from hypothetical jig pose:

$$V_{icc}^2 = R_{jc} T_{ijj} + T_{jcc}$$

Spatial Accuracy

Closest point of intersection of two vectors:

$$0 = \left(\bar{P}_1 + c_1\bar{D}_1 - (\bar{P}_2 + c_2\bar{D}_2)\right) \bullet \bar{D}_1$$
$$0 = \left(\bar{P}_1 + c_1\bar{D}_1 - (\bar{P}_2 + c_2\bar{D}_2)\right) \bullet \bar{D}_2$$
$$c_2 = \frac{(\bar{P}_2 - \bar{P}_1) \bullet \bar{D}_2 - (\bar{D}_1 \bullet \bar{D}_2)(\bar{P}_2 - \bar{P}_1) \bullet \bar{D}_1}{(\bar{D}_1 \bullet \bar{D}_2)^2 - 1}$$
$$c_1 = (\bar{P}_2 - \bar{P}_1) \bullet \bar{D}_1 + c_2(\bar{D}_1 \bullet \bar{D}_2)$$

Total miss distance for two checkers:

$$M_1 = \| \bar{P}_1^a + c_1^a \bar{D}_1^a - (\bar{P}_2^a + c_2^a \bar{D}_2^a) \| + \| \bar{P}_1^b + c_1^b \bar{D}_1^b - (\bar{P}_2^b + c_2^b \bar{D}_2^b) \|$$

Difference between calculated checker distance versus actual distance:

$$M_2 = D - \| \bar{P^a} - \bar{P^b} \|$$

Preliminary Results