Institute of Robotics and Mechatronics
German Aerospace Center (DLR) www.DLR.de

More Accurate Pinhole Camera Calibration with Imperfect Planar Target

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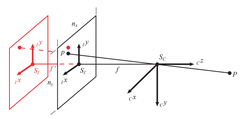
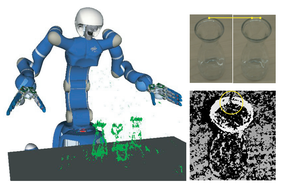
What is *essentially* camera calibration?

- **Objective**: Parametrization of an adequate system model.
- **Method**: Minimize discrepancies between expected (model-based) and actual operation.

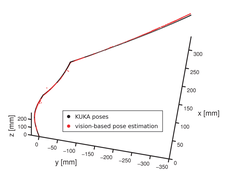


Is it a solved problem? *NO.*

Stereo vision



Visual odometry

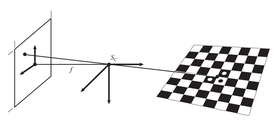


Narrow AOV, etc.

Standard method

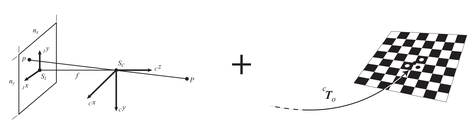
Zhang/Sturm&Maybank, 1999

- *Extends* the required models to extrinsic pose w.r.t. a **known target**.
- Restricts the target to **2-D** (easier, more accurate, and a simpler initialization).



1) Direct initialization from homographies.
2) Nonlinear optimization.

It works because all effects are distinct from each other:

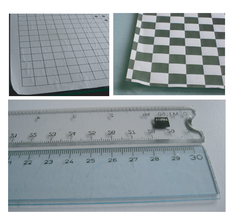


(Scaling) (*Perspective warping* + scaling)

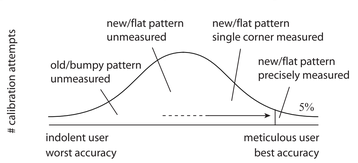
Problem statement

A "planar" calibration target …

- is inaccurate in size *and layout*,
- deforms when being measured,
- deforms in time,
- gauge accuracy is limited.

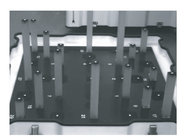


Relaxing this requirement of known target geometry we aim at pushing all calibration attempts towards highest accuracy :

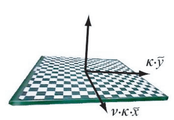


Previous works and their limitations

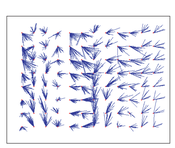
1. **Lavest, Viala, and Dhome**. "*Do We Really Need an Accurate Calibration Pattern to Achieve a Reliable Camera Calibration?*" ECCV 1998.
   - In 3-D, therefore
   - laborious initialization.
   - Redundant parametrization.



2. **Strobl and Hirzinger**. "*More Accurate Camera and Hand-Eye Calibrations with Unknown Grid Pattern Dimensions*," ICRA 2008.
   - In 2-D.
   - Tidy separation of aspect ratio and abs. scale.
   - Insufficient when irregular patterns.

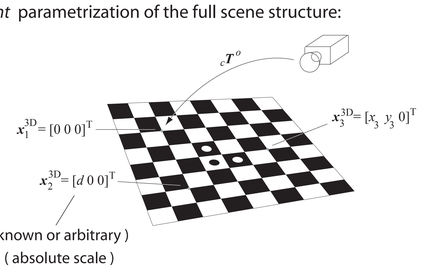


3. **Albarelli, Rodolá, and Torsello**. "*Robust Camera Calibration using Inaccurate Targets*," BMVC 2010.
   - In 2-D.
   - Full structure optimization.
   - Redundant parametrization, thus iterative.



Proposed method

Joint optimization of intrinsic camera parameters and a *tight* parametrization of the full scene structure:



- Arbitrary choice of the fixed corners as long as they are non-collinear.
- Optimization parameters are:

intrinsic parameters for *C* cameras,	(e.g. (5+2) x *C*)
C-1 transformations between cameras,	(6 x (*C*-1))
N extrinsic poses, and	(6 x *N*)
M-3+2/3 corner points.	(*M* x 3 - 7)

- The use of the Jacobian sparsity pattern is encouraged as $M >> N$.

Algorithm

1. Linear least-squares initialization from 2-D homographies (extension for insensitivity to aspect ratio and absolute scale).

$$ {}_n\widehat{\boldsymbol{H}} \propto \boldsymbol{A}[{}_n\boldsymbol{r}_1\ {}_n\boldsymbol{r}_2\ {}_n\boldsymbol{t}] \quad \begin{cases} \boldsymbol{h}_1^T\,\boldsymbol{\omega}_\infty\,\boldsymbol{h}_1 = \boldsymbol{h}_2^T\,\boldsymbol{\omega}_\infty\,\boldsymbol{h}_2 \\ \boldsymbol{h}_1^T\,\boldsymbol{\omega}_\infty\,\boldsymbol{h}_2 = 0 \end{cases} $$

2. Standard, nonlinear least-squares optimization (optional).
3. *Tight*, full nonlinear least-squares optimization (potentially extended to stereo constraints).

$$ \widehat{\boldsymbol{\Omega}}_\star^{\oplus} = \arg\min_{\widehat{\boldsymbol{\Omega}}^{\oplus}} \sum_{c=1}^{C}\sum_{n=1}^{N}\sum_{i=1}^{M} ||{}_n^c\tilde{\boldsymbol{m}}_i - {}_n^c\hat{\boldsymbol{m}}_i(\widehat{\boldsymbol{\Omega}}^{\oplus},\, d)||^2 $$

4. Hand-eye calibration with initially unknown absolute scale.

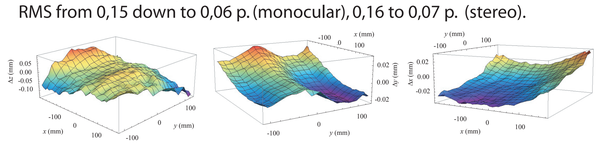
$$ \{{}_t\widehat{\boldsymbol{T}}_\star^c, {}_b\widehat{\boldsymbol{T}}_\star^o, \hat{d}_\star\} = \arg\min_{{}_t\widehat{T}^c,\, {}_b\widehat{T}^o,\, d} \sum_{n=1}^{N} \mathcal{O}_n(\Phi({}_c\widehat{\boldsymbol{T}}_\star^o,\, \hat{d}),\, {}_b\bar{\boldsymbol{T}}^t,\, \ldots) $$

Observe:

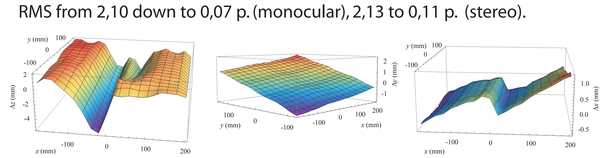
- d is required if stereo camera calibration is intended (potential hand-eye calibration waives the requirement).
- The calibration target has to be rigid or at least static.
- Points have to be imaged twice (e.g. including general views).

Results

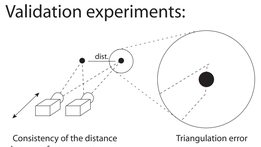
Best case scenario (precision plate).
RMS from 0,15 down to 0,06 p. (monocular), 0,16 to 0,07 p. (stereo).

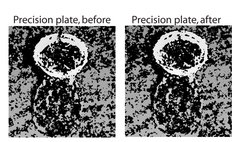


Worst case scenario (wrinkled, unmeasured A3 paper).
RMS from 2,10 down to 0,07 p. (monocular), 2,13 to 0,11 p. (stereo).

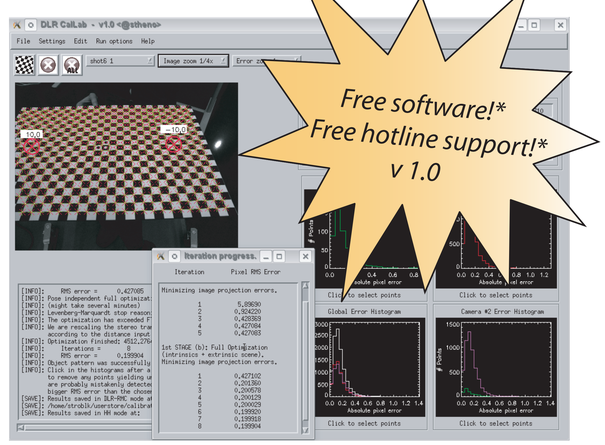


Validation experiments:





Software available



DLR CalDe and DLR CalLab toolbox
`http://www.robotic.dlr.de/callab`

* for academic purposes

1st IEEE Workshop on Challenges and Opportunities in Robot Perception, 13th International Conference in Computer Vision, November 12th, 2011. Barcelona, Spain