An Automatic Method for Adjustment of a Camera Calibration Room

Theory, algorithms, implementation, and two advanced applications.

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Outlines

Which application needs a calibration (presentation)

Camera calibration literature review (paper)

- Background.

Our initial goals that we started from

- Overview of aims
- The proposed coded-target, "*design principles*" and "automatic detection".

Some formulation very briefly

- Photogrammetric basis
- Material: calibration room and cameras.
- Results.
- +More results.
- Achieved aims

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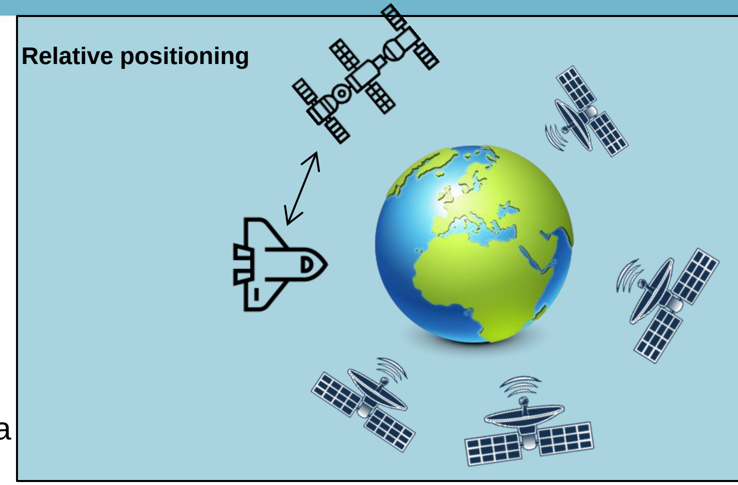
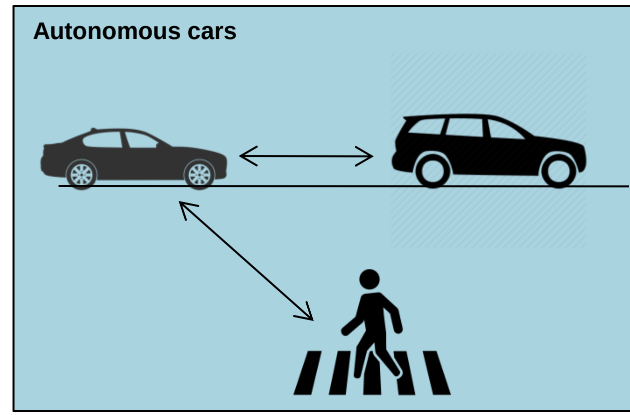
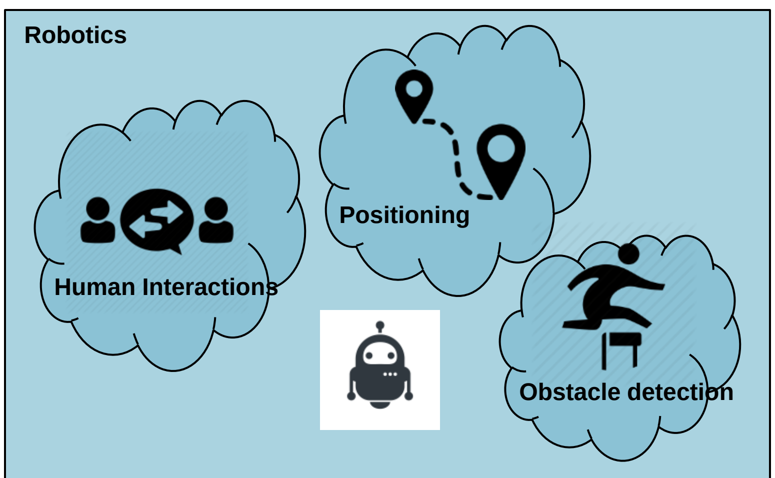
Background

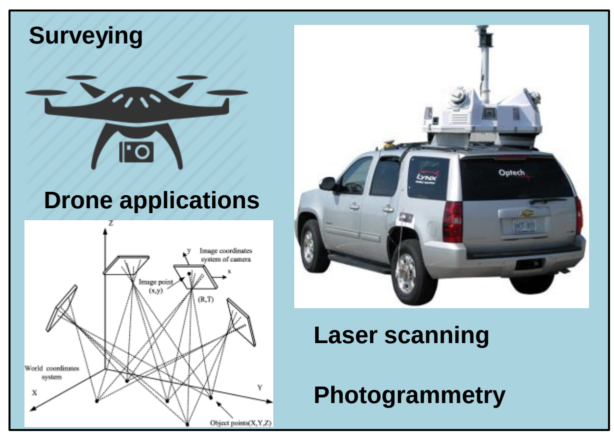
- Machine vision is becoming a part of our everyday lives.
- A revolutionary progress happened in development of new camera technologies.
- Very advanced cameras such as multispectral cameras are cheaply accessible.
- Multi camera systems has found their was in many applications such as robotics, car navigation systems, entertainment applications and even space applications such as spacecraft docking navigation systems, and satellite navigation systems.

….., Therefore, novel camera calibration paradigms are valuable.









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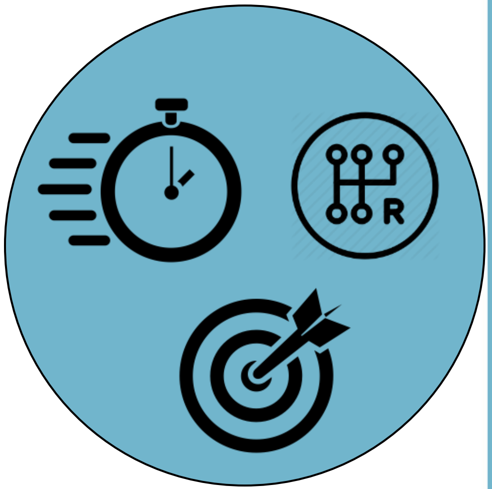
Overview of Aims



- Designing easy-to-use targets:
  - "*<u>Good-visibility</u>*" in a distance range of (30cm-4m) .
  - Containing an "*<u>embedded ID</u>*".
  - Embedding a "*<u>scale</u>*".
  - Relative ease of *"<u>automatic detection</u>"*.
- Fast automatic reading of targets.
- Fast reconstruction of camera motions and a scene.
- Expressing uncertainties based on standard statistical models.
- Calibrating state-of-the-art single frame and multi-projective cameras efficiently in terms of *<u>accuracy/precision</u>*, *<u>calculation time</u>*, and *<u>processing power consumption</u>*.

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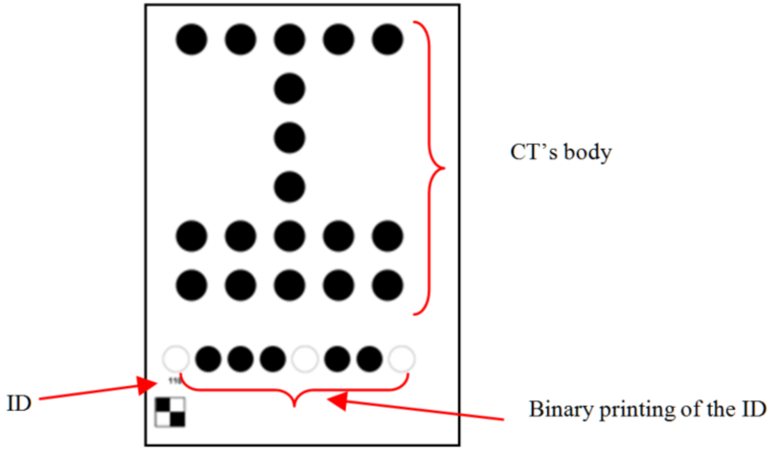
The Proposed Coded-Target, Design Principles and Automatic Detection

- **Design**

- Main structure is rotation invariant.
- An ID is embedded as a binary code.
- Topological structure is easy to detect even under conditions that the target is partly visible.
- A high sub-pixel accuracy is accessible based on LS.



- **Automation**

- Maximally stable extremal regions (mser) is first run to find initial estimation of dots.
- Least-square fit is used to achieve sub-pixel accuracy of extracted ellipses.
- The topological structure is coded to find targets from a set of detected ellipses.
- Almost all detected targets (over 99.9%) are correct. No outlier! Some still missing ;)

Photogrammetric Basis

- Standard Brown's model is used as the interior orientation model.

$$x_1 = \frac{(x)_{t_1} - PP_x}{f},\ y_1 = \frac{(y)_{t_1} - PP_y}{f},\ r^2 = \sqrt{x_1^2 + y_1^2},\ Rad = (1 + K_1.r^2 + K_2.r^4 + K_3.r^6)$$

$$(x_n)_{t_1} = x_1.Rad + 2.P_1.x_1.y_1 + P_2.(r^2 + 2(x_1)^2) - \delta.x_1 + \lambda.y_1$$

$$(y_n)_{t_1} = y_1.Rad + 2.P_2.x_1.y_1 + P_1.(r^2 + 2(y_1)^2) \qquad + \lambda.x_1$$

- First image considered as the center of the local coordinate system.
- Co-planarity equation is used to connect stereo pairs. $E = [(X_0)_t]_x.R_t$
- Collinearity equation is used as the foundation of the BBA.

$$x_t = -\frac{M_{t(1,:)}.(X-(X_0)_t)}{M_{t(3,:)}.(X-(X_0)_t)},\ y_t = -\frac{M_{t(2,:)}.(X-(X_0)_t)}{M_{t(3,:)}.(X-(X_0)_t)},$$

- Errors are propagated from "*observations and possible unknowns with a priori known std*" to "*the unknowns*".

$$F\left((f, \mathbf{PP}, \mathbf{K}, \mathbf{P}, \sigma, \lambda), R_{(\omega,\phi,\kappa)_{(t_1:t_m)}}, X_{0\,(t_1:t_m)}\right) = 0$$

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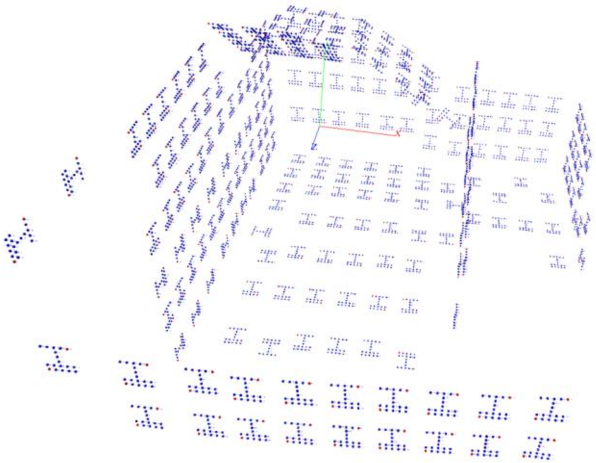
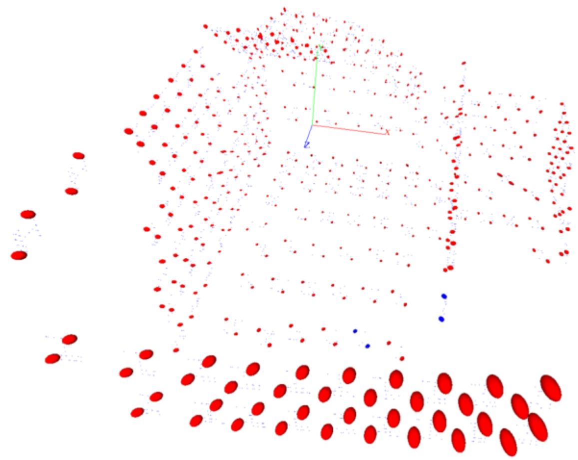
Calibration Room and Cameras

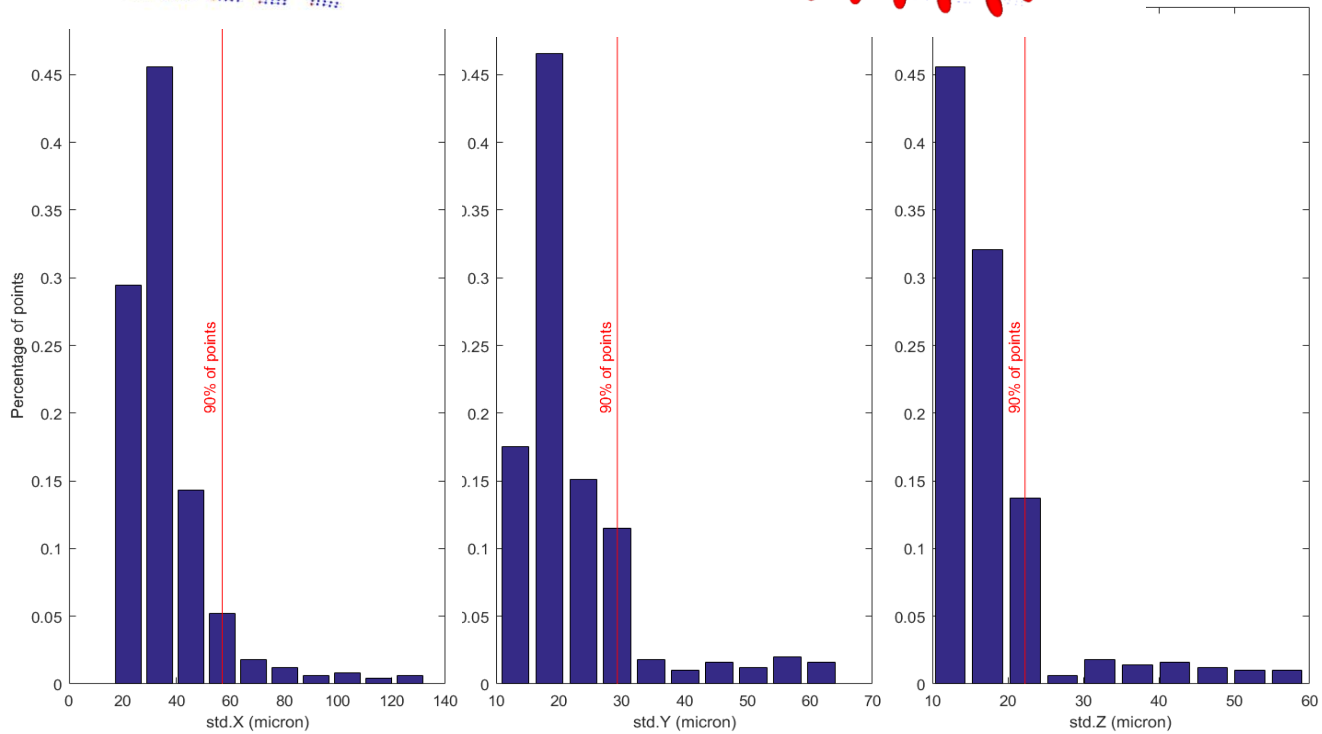
- 215 printed coded-targets have been attached to the side walls ceiling and floor.
- Two projective cameras have been used for data collection:
  - (A) Canon EOS-6D, sensor 20MPix =5472x3648 , Lens=Canon EF 24mm f/2.8 IS USM, focal length: FL=20.6mm.
  - (B) Samsung NX300, sensor=20MPix 5472x3648 , Lens: Samsung ultra wide angle lens f/2.4, FL=16.34mm.

- Seven datasets each containing 50-90 images were captured by the EOS-6D camera. Two cross-check data sets of 50 and 80 images were taken by NX300 camera.

Results: 1-Calibration Room







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Results: 2-Camera IOs, positions, error ellipses

No	Param. Name	value	Std.	value	Std.
		Canon EOS-6D		Samsung NX300	
1	Focal Length (px.)	3157.65	1.22E-01	3806.53	2.76E-01
2	Focal Length (mm)	20.65	7.96E-04	16.34	1.18E-03
3	Principal Point x dir.(px.)	2754.72	1.57E-01	2685.69	3.86E-01
4	Principal Point y dir.(px.)	1516.57	1.60E-01	1833.81	3.56E-01
5	K1	8.34E-02	1.35E-04	1.57E-02	2.30E-04
6	K2	-7.41E-02	3.57E-04	-2.53E-02	7.86E-04
7	K3	1.06E-02	2.80E-04	1.26E-02	8.19E-04
8	P1	3.66E-04	1.30E-05	-6.72E-04	2.50E-05
9	P2	9.30E-05	1.50E-05	1.60E-03	2.80E-05
10	Scale factor	1.60E-05	1.10E-05	9.90E-05	1.80E-05
11	Shear factor	-1.06E-04	5.00E-06	-1.20E-05	8.00E-06

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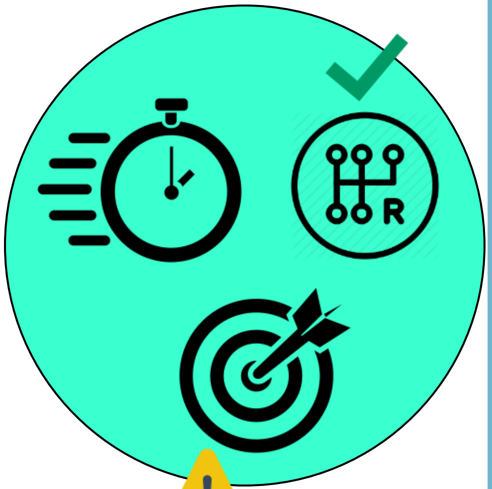
Achieved Aims



- Designing easy-to-use targets: ✓
  - Good-visibility. ✓ (*Not suitable for all cameras, multi-scaling is required*)
  - Containing an Embedded ID. ✓
  - Embedding a scale. ✓
  - Relative ease of automatic detection (MATLAB and C++ implementation). ✓
- Fast automatic reading of targets (***less than 30 min for 100 image***) ✓
- Fast reconstruction of camera motions and the scene ✓
- Expressing uncertainty based on standard statistical models ✓
- Calibrating state-of-the-art single frame and multi-projective ✓ cameras in an efficient manner in terms of accuracy/precision, calculation time, and processing power.

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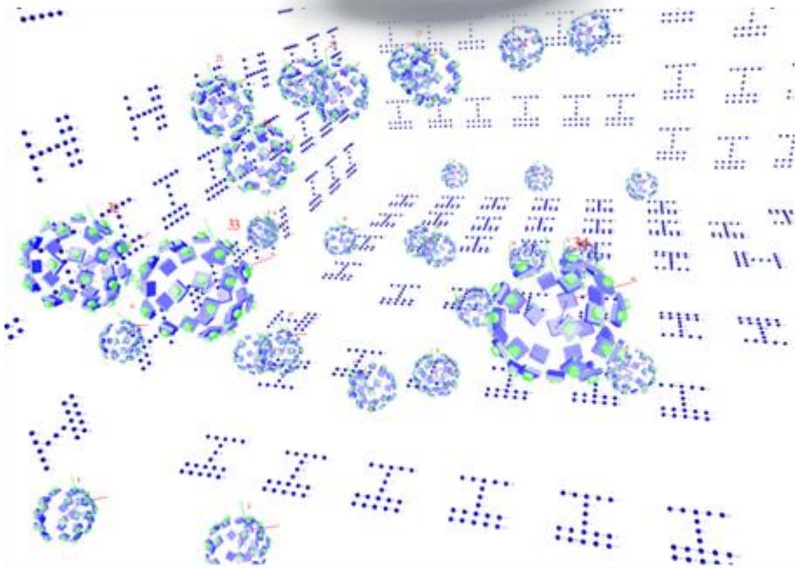
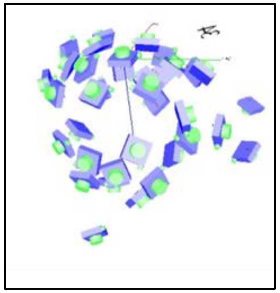
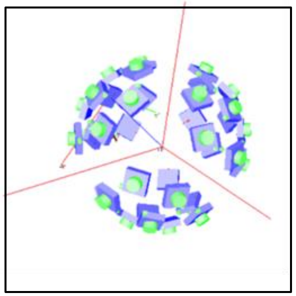
Multi-projective camera Calibration Using The Rigid Calibration room (Case 1: Panono)

- Panono is selected as MPC_36 .
- Input:
  - 80 Panono shots.
  - The calibrated calibration room as the rigid body.
- Output
  - 36 sets of Interior orientation parameters with their corresponding uncertainties.
  - 35 Camera relative pos/ori with respect to the first camera with the corresponding uncertainties.
  - Position/orientation of MPC shots.

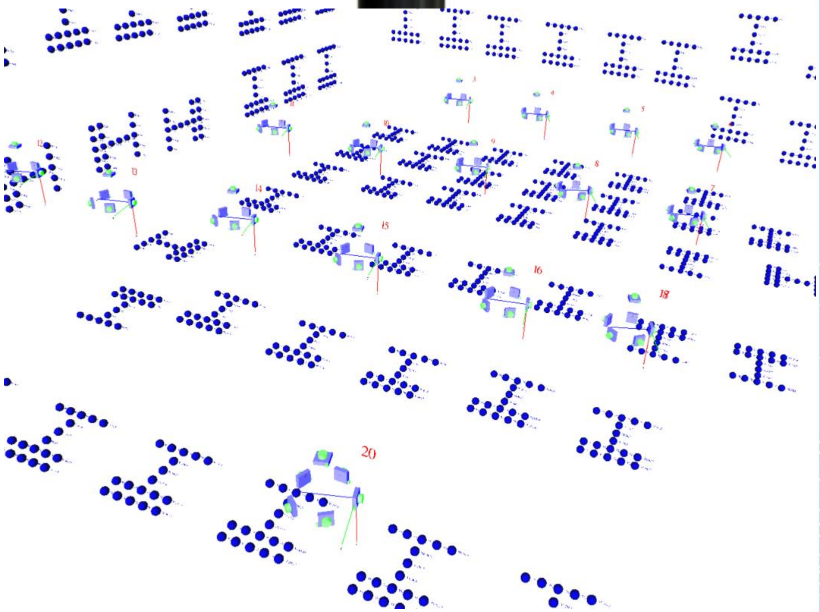




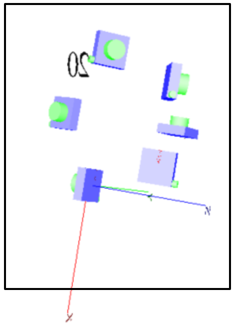


Multi-projective camera Calibration Using The Rigid Calibration room (Case 2: LadyBug)

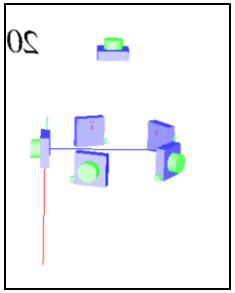
- Input:
  - LadyBug is selected as MPC_6 .
  - The calibrated calibration room as the rigid body.
- Output
  - 6 set of Interior orientation parameters with the corresponding uncertainties.
  - 5 Camera relative pos/ori with respect to the first camera with the corresponding uncertainties.
  - Position/orientation of MPC shots.



Initial



Final



What is Next?

- Improving the target design to have multi-scale targets.
- Calibrating state-of-the-art multi-spectral cameras used for drone technologies with the underlying approach.
- Integrating omni-directional lens model.
- Improving completeness of the automatic target detector.

Thanks for listening!

More information could be found at:

http://www.mv.helsinki.fi/home/khoramsh/

Any Question???

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