SIMULTANEOUS GEOMETRIC AND COLORIMETRIC CAMERA CALIBRATION

Workshop Farbbildverarbeitung 2010

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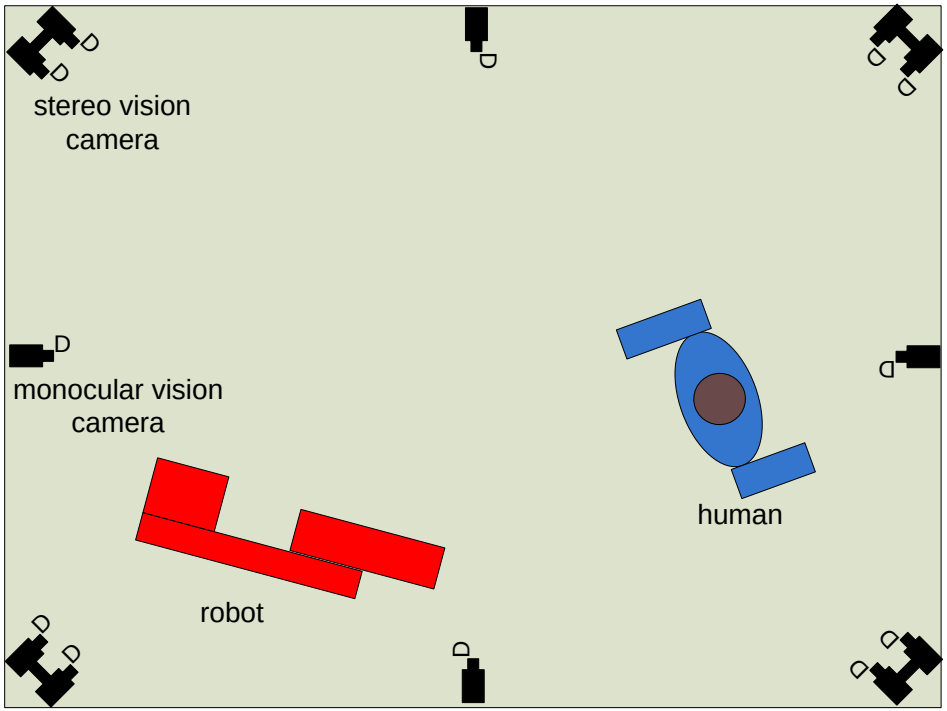
Outline

SIMULTANEOUS GEOMETRIC AND COLORIMETRIC CAMERA CALIBRATION

- Motivation
- Calibration Target
- Target Feature Detection
- Geometric Calibration
- Stereo Rectification
- Color Calibration
- Conclusion

Application Scenario: Robot Work Area



Vision based safety system:

Avoiding collisions between robots and humans!

3D scene modeling

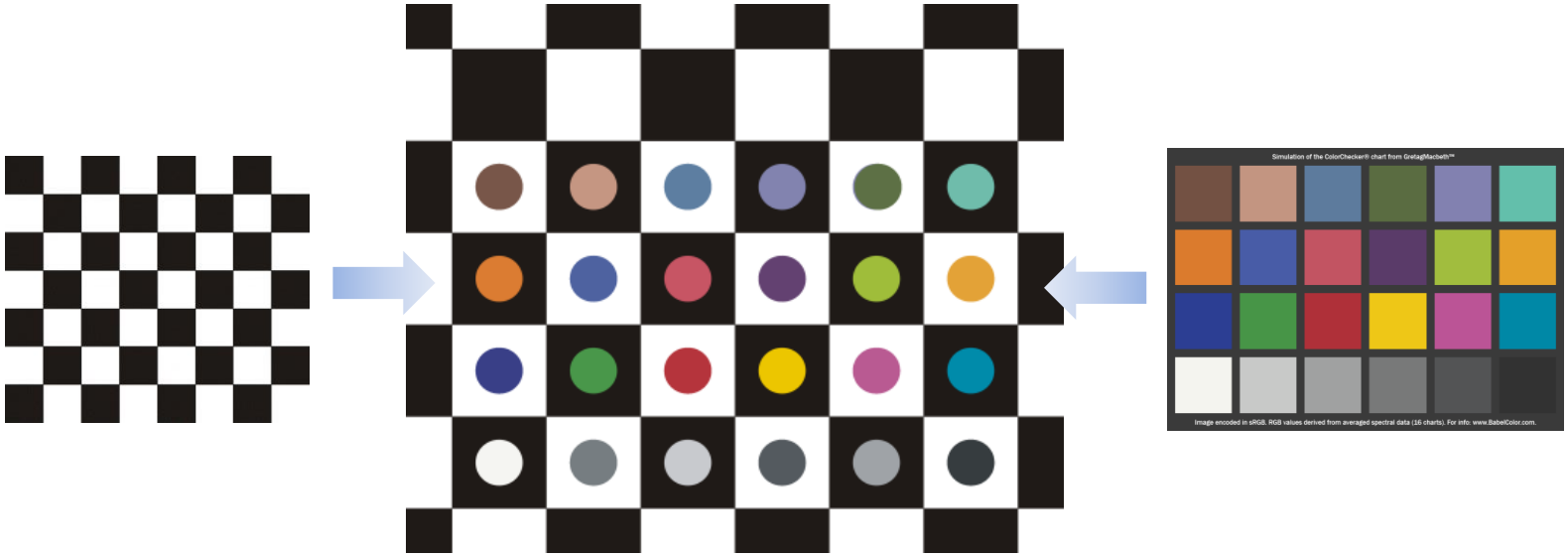
- Redundant scene observation from multiple points of view
- Stereo vision for more robust object recognition

Requirements

- Unified coordinate system for all sensors
- Unified colorimetric perception between all sensors

Geometric and Colorimetric Camera Calibration

Chessboard Calibration Target With Colorimetric Features



Geometric features

- Different parity in number of edges in horizontal and vertical direction [1]

Orientation is clearly detectable

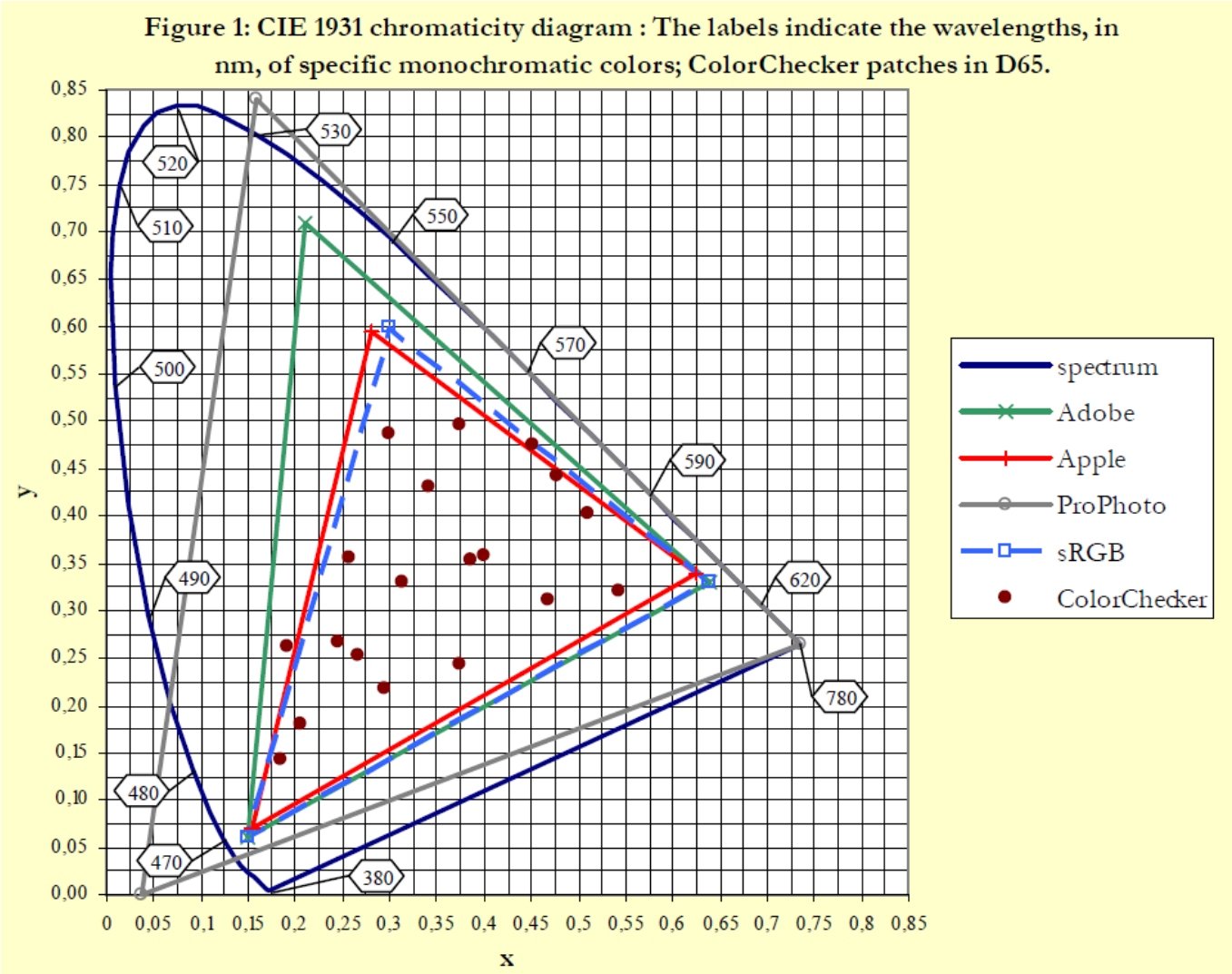
Colorimetric features

- 24 circles filled with well distributed reference colors (natural and primary colors as well as grey-balanced fields) in the style of the Macbeth [2] color checker

[1] Jean-Yves Bouguet. (2010, July) Camera Calibration Toolbox for Matlab. [Online]. http://www.vision.caltech.edu/bouguetj/calib_doc/index.html

[2] C. S. McCamy, H. Marcus, and J. G. Davidson, "A Color-Rendition Chart," *Journal of Applied Photographic Engineering, vol. 2, no. 3, pp. 95-99, Summer 1976.*

Values Of The ColorChecker



[3] Danny Pascale, "RBG coordinates of the Macbeth ColorChecker," The BabelColor Company, Montreal, Quebec, Canada, Comparison 2006.

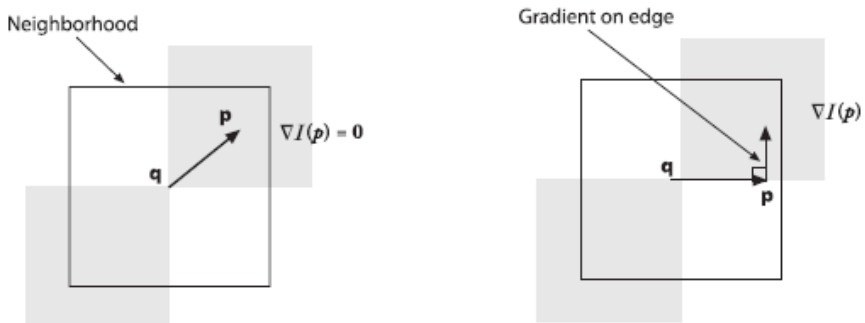
Detecting Edges On The Chessboard Using OpenCV

1. Step: rough edge detection [4]

- Adaptive threshold binarization
- Separate black squares by dilatation of white squares
- Find and simplify contours to 4 edge-points at each black square

2. Step: sub pixel accurate edge detection [4]

- Using the fact, that the dot product of two orthogonal vectors is zero
- Consider all points within a neighborhood around the real corner position Q
- Iterative solution of a linear system of equations

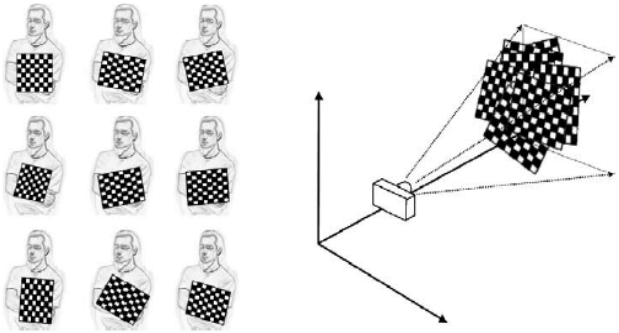


$\mathbf{p_i}$ – position vector to point P_i
$\mathbf{q}$ – position vector to point Q

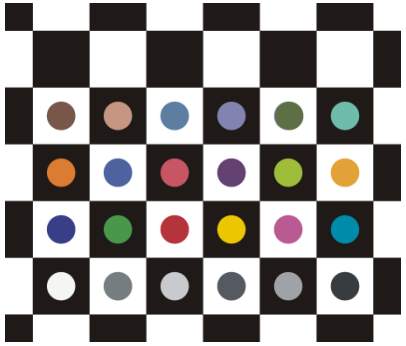
$$\nabla I(P_i)^T \cdot (\vec{p_i} - \vec{q}) = 0$$

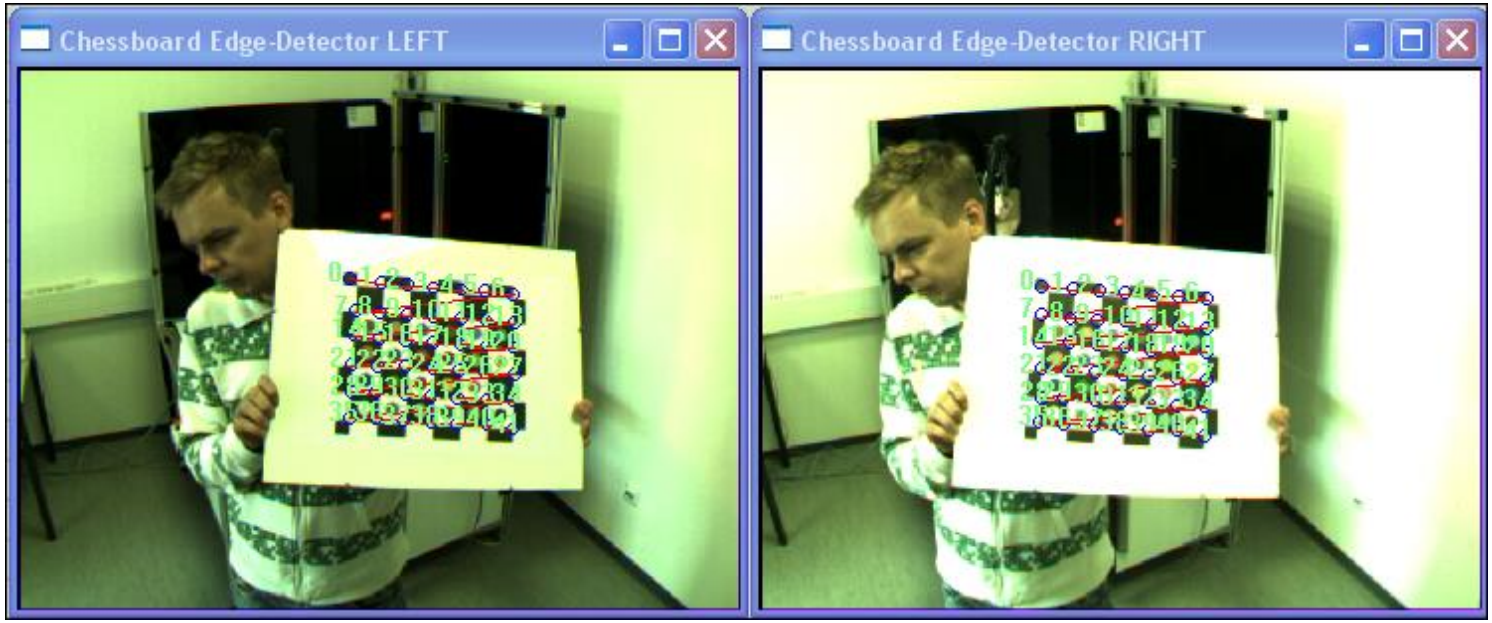
[4] Gary Bradski and Adrian Kaehler, *Learning OpenCV. Sebastopol, USA/CA: O´Reilly Media, 2008*

Detecting Edges On The Chessboard Using OpenCV



Multipose-Calibration

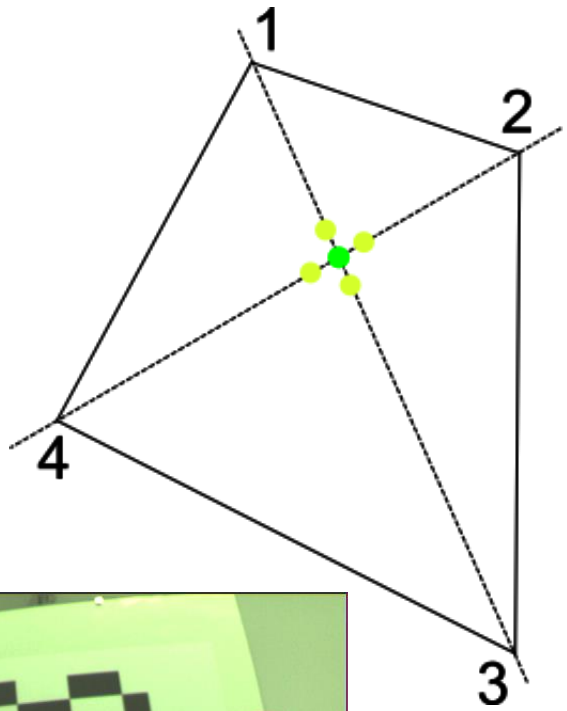




Detecting Color Features

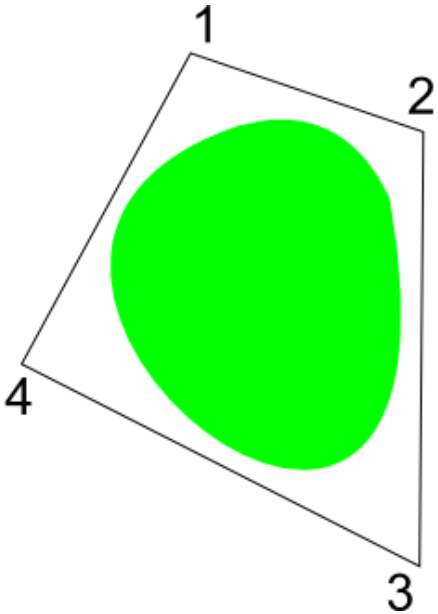
Calculating the start color value from each square

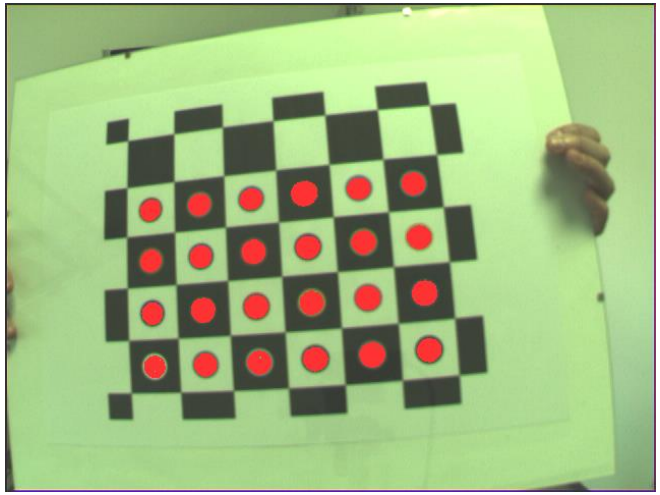
- Middle position of the chessboard square
- Median value from direct neighborhood



Recursive region growing

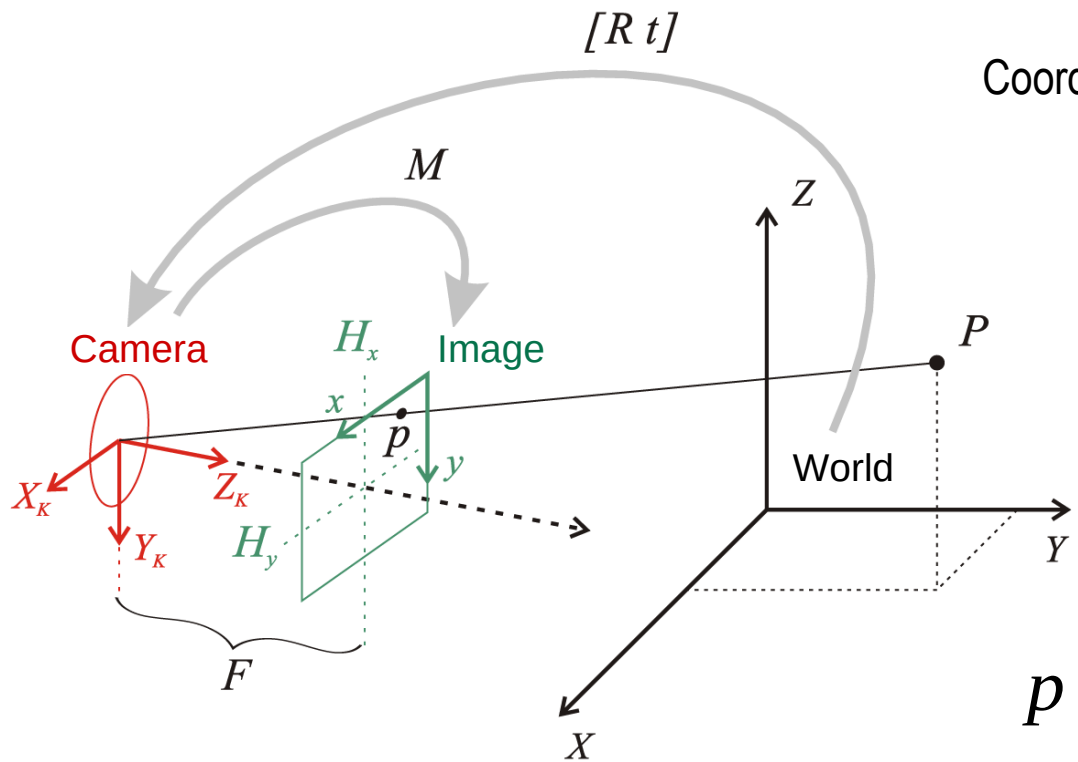
- Using a uniform criterion as a tolerance threshold





Average the color values from the segmented region

Camera Parameters



Coordinate transformation

World

$$[R \quad t]\cdot P$$

Camera

$$M = \begin{pmatrix} f_x & 0 & H_x \\ 0 & f_y & H_y \\ 0 & 0 & 1 \end{pmatrix}$$

Image

$$p = M \cdot [R \quad t]\cdot P$$

Intrinsic camera parameters

Hx, Hy – Principal point coordinates

F – Focal length

Extrinsic camera parameters

R – Rotation matrix

t – Translation vector

[5] Roger Y. Tsai, "An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision," *IEEE Journal of Robotics and Automation*, vol. 3, no. 4, pp. 323-344, August 1987.

[6] Zhengyou Zhang, "A Flexible New Technique for Camera Calibration," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 11, pp. 1330-1334, November 2000.

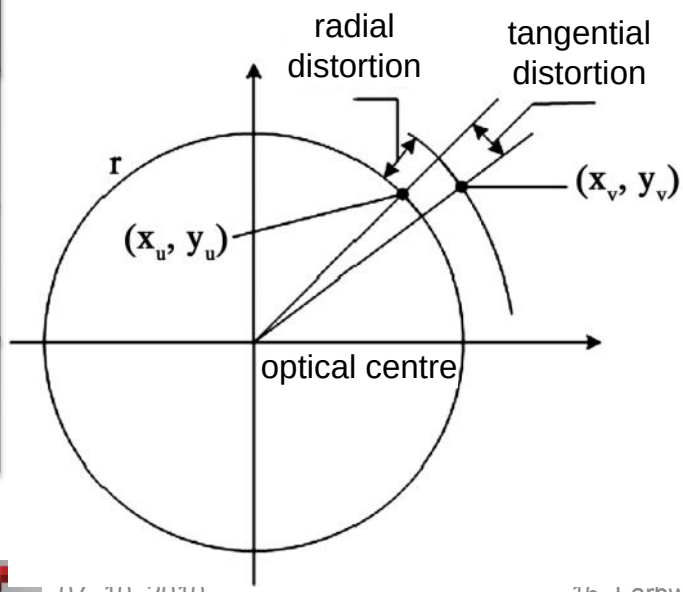
Brown-Conrady-Distortion-Model

radial distortion + tangential distortion

$$x_v = x_u \cdot \overbrace{\left(1 + k_1 r^2 + k_2 r^4 + k_3 r^6\right)}^{\text{radial}} + 2 p_1 x_u y_u + p_2 (r^2 + 2 x_u^{\ 2})$$

$$y_v = y_u \cdot \left(1 + k_1 r^2 + k_2 r^4 + k_3 r^6\right) + \underbrace{p_1 (r^2 + 2 y_u^{\ 2}) + 2 p_2 x_u y_u}_{\text{tangential}}$$

$$r^2 = x_u^{\ 2} + y_u^{\ 2}$$



Distortion parameters

k1, k2, k3 - radial distortion coefficients

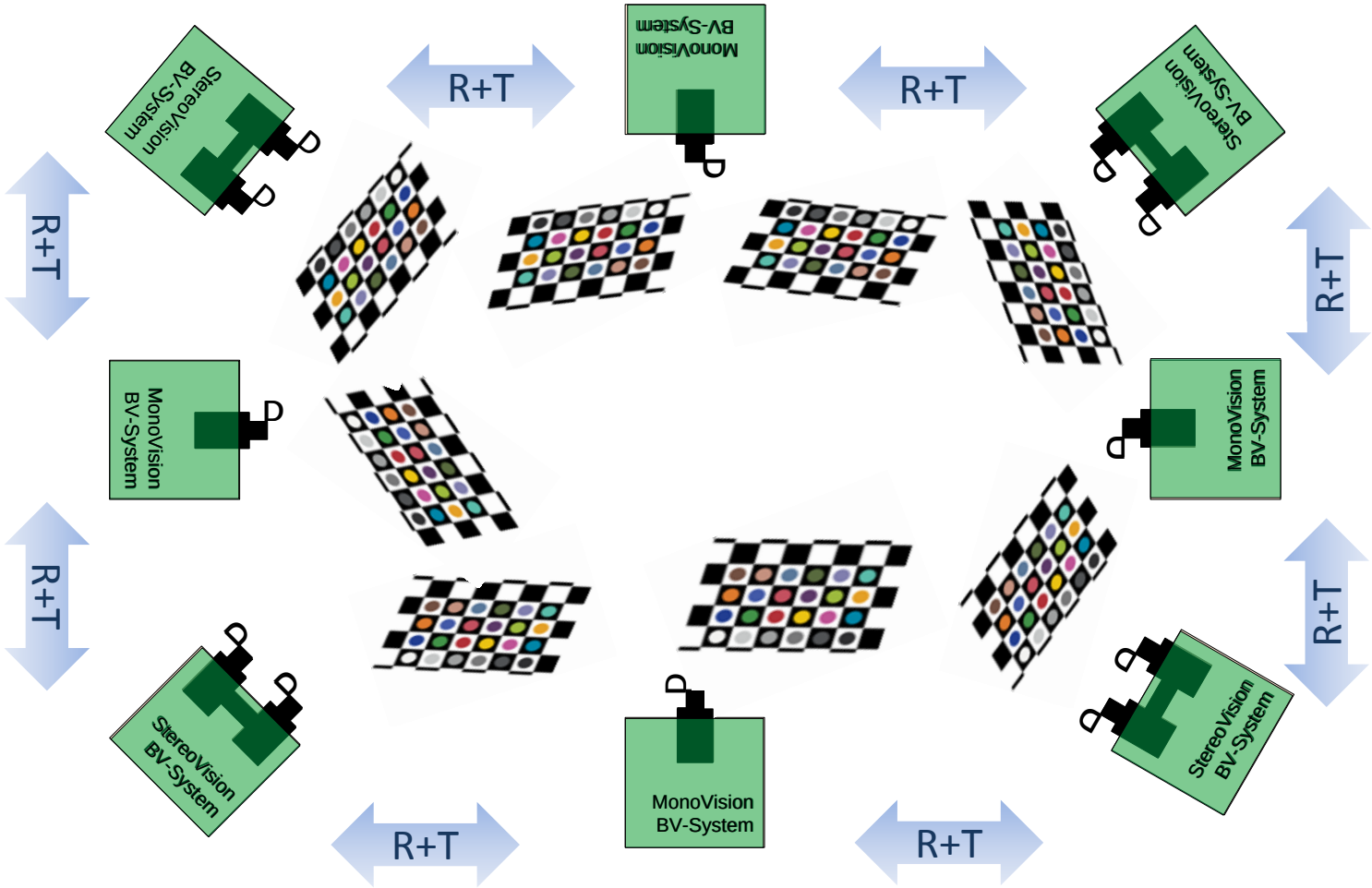
p1, p2 - tangential distortion coefficients

[7] Alexander Eugen Conrady, "Decentering lens systems," *Monthly notices of the Royal Astronomical Society*, vol. 79, pp. 384-390, April 1919.

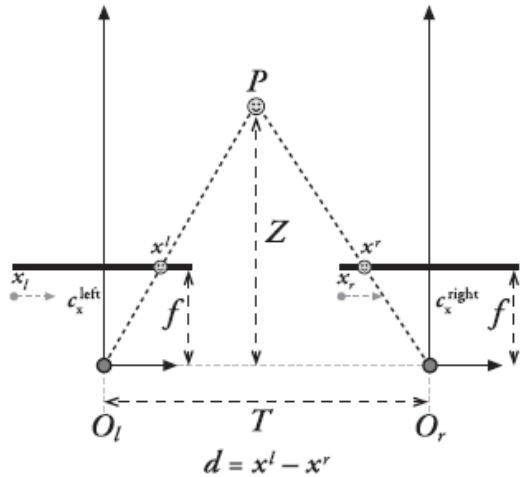
[8] Duane C. Brown, "Decentering Distortion of Lenses," *Photometric Engineering*, vol. 32, no. 3, pp. 444-462, 1966.

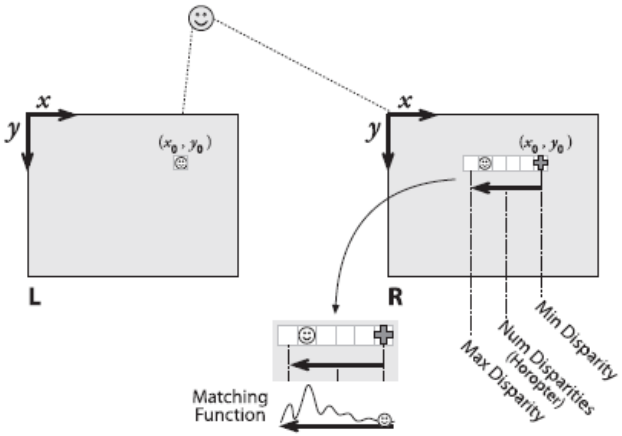
Overall Calibration Procedure

- Motivation
- Calibration Target
- Target Feature Detection
- **Geometric Calibration**
- Stereo Rectification
- Color Calibration
- Conclusion



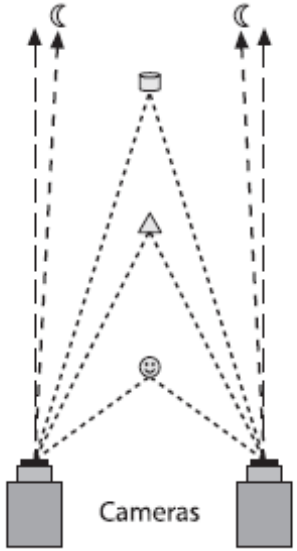
Stereo Rectification[4]



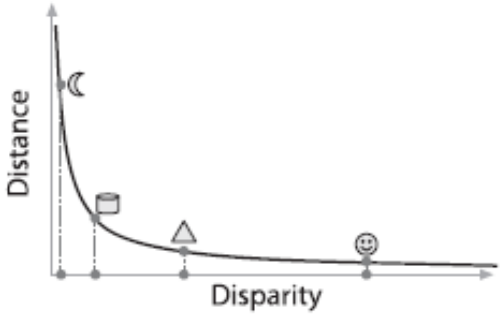


Extraction of depth information

- Assuming a standard stereo geometry
- Determination of the horizontal mismatch (disparity) from a stereoscopic view (Correspondence analysis)
- Calculating the distance by simple triangulation



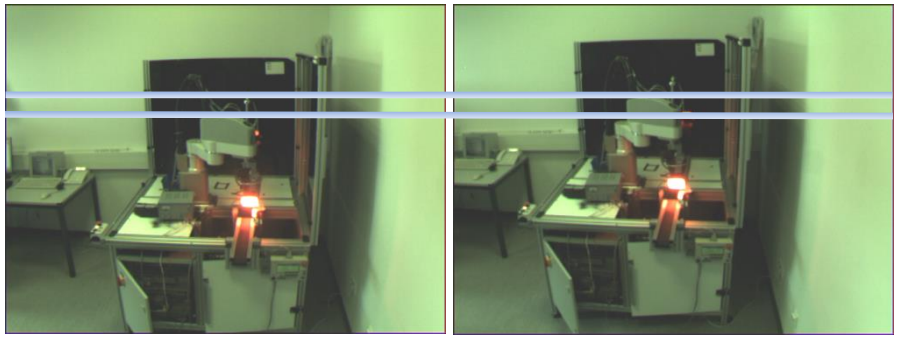
$$Z = \frac{fT}{x^l - x^r}$$



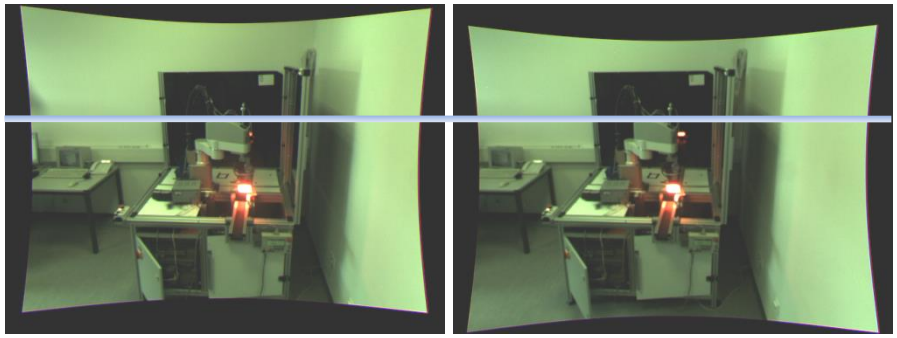
[4] Gary Bradski and Adrian Kaehler, *Learning OpenCV. Sebastopol, USA/CA: O´Reilly Media, 2008*

Stereo Rectification[4]

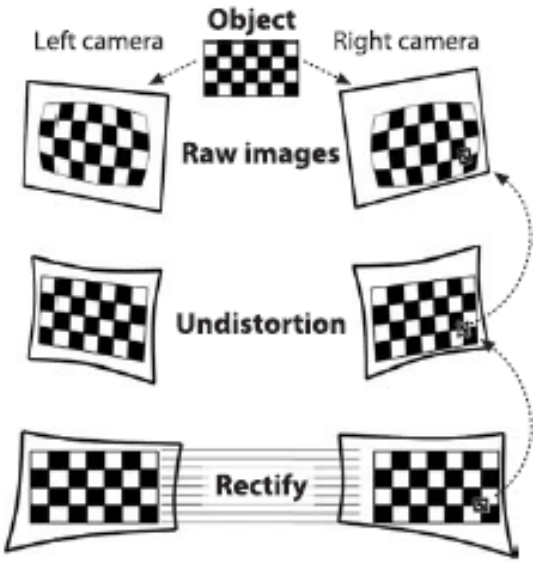
left right



unrectified image



rectified images



[4] Gary Bradski and Adrian Kaehler, *Learning OpenCV. Sebastopol, USA/CA: O´Reilly Media, 2008*

Color Calibration

Target based global color calibration[9]

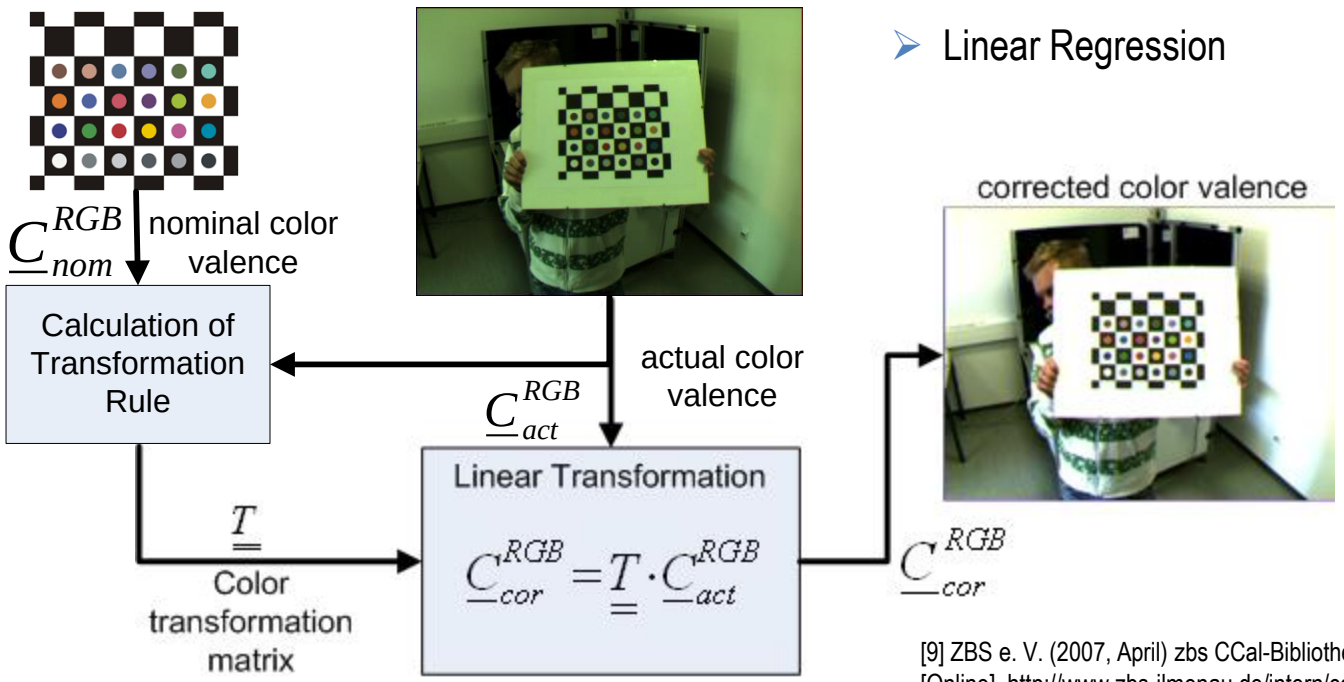
- Corresponding nominal and actual color values
- Calculation of the transformation rule which causes the smallest middle aberration

Non-linear transformation model

- Polynomial regression

Linear transformation models

- Scaling (+Offset)
- Linear Transformation
- Linear Regression



[9] ZBS e. V. (2007, April) zbs CCal-Bibliothek Benutzerdokumentation. [Online]. http://www.zbs-ilmenau.de/intern/ccalc/ZBSColCalib.pdf

Conclusion

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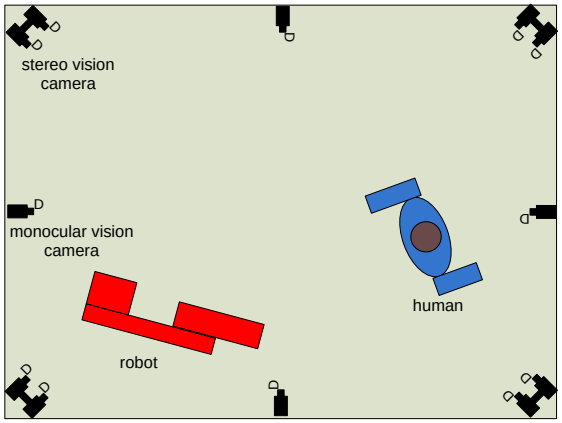

Requirements to 3D scene modeling

- Unified coordinate system for all sensors
- Unified colorimetric perception between all sensors

Geometric and Colorimetric Camera Calibration

- Using a chessboard target with integrated color markers
- Sub pixel accurate edge detection of the chessboard squares
- Calculating intrinsic camera parameters, distortion coefficients and geometric relations to adjacent sensors from multiple target poses
- Calculate rectification parameters for stereo vision systems
- Target based color calibration

Available as an ANSI C conform software library