Robotics
JACOBS UNIVERSITY

UNDERWATER CAMERA CALIBRATION WITH THE PINAX MODEL

A NEW CAMERA MODEL ALLOWING ACCURATE IN-AIR CALIBRATION OF CAMERAS IN FLAT PANE UNDERWATER HOUSINGS

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and

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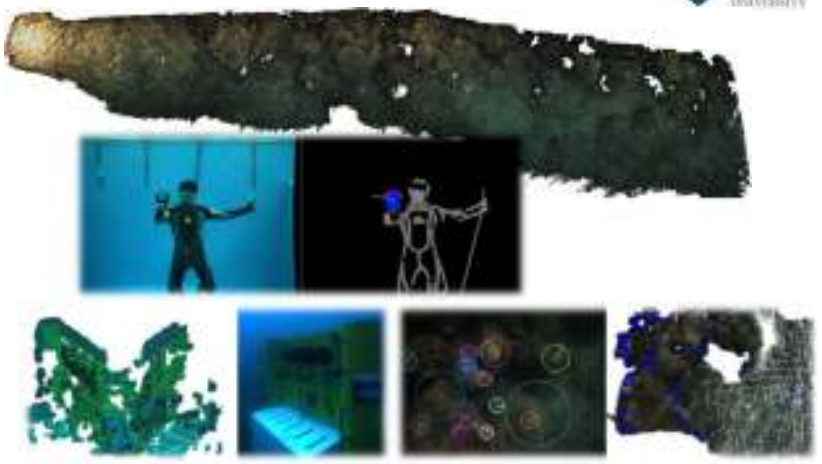
Underwater machine vision applications

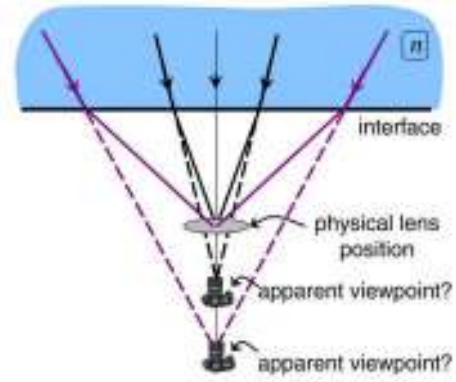


Flat pane vs dome housings

- Easy design
- Cheap
- Well protected glass
- Refraction-based effects

- No additional distortions
- Expensive
- Manual camera positioning
- Prone to scratches

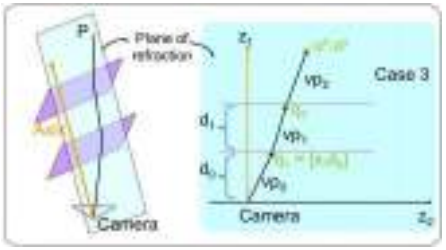
Camera behind the flat panel as an axial camera



T. Treibitz, Y. Schechner, C. Kunz, and H. Singh, "Flat refractive geometry," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 34, no. 1, pp. 51–65, Jan 2012.

Projection function of the axial camera

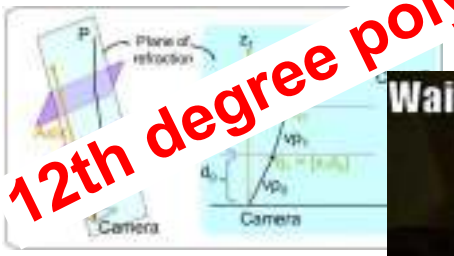
$$(k_1^2 D_1 + k_2^2 D_2 - k_3^2 D_1 D_2)^2 - 4k_1^2 k_3^2 D_1 D_2 = 0$$



$$k_1 = x(d_0 + d_1 - u^v)$$
$$k_2 = (u^v - x)$$
$$k_3 = -d_1 x$$
$$D_1 = d_0^2 n_y^2 + n_y^2 x^2 - x^2$$
$$D_2 = d_0^2 n_w^2 + n_w^2 x^2 - x^2$$

A. Agrawal, S. Ramalingam, Y. Taguchi, and V. Chari, "A theory of multi-layer flat refractive geometry," in *Computer Vision and Pattern Recognition (CVPR), 2012 IEEE Conference on*, June 2012, pp. 3346–3353.

Projection function of the axial camera



$$k_1 = x(d_0 + d_1 - u^v)$$

12th degree polynomial

A. Agrawal, S. Ramalingam, Y. Taguchi, and V. Chari, "A theory of multi-layer flat refractive geometry," in *Computer Vision and Pattern Recognition (CVPR), 2012 IEEE Conference on*, June 2012, pp. 3346–3353.

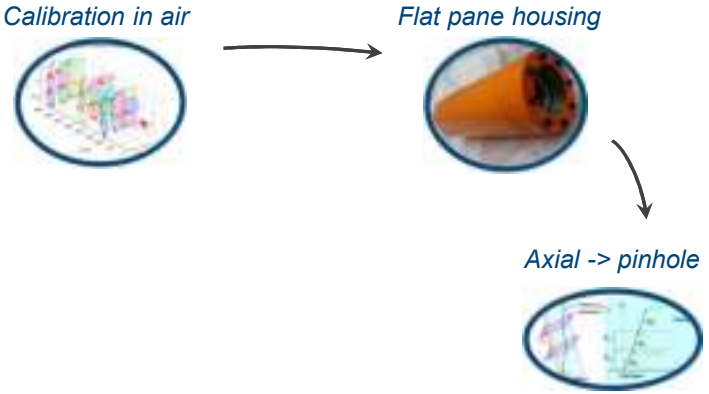
Pinax model for fast and accurate image rectification

Calibration in air

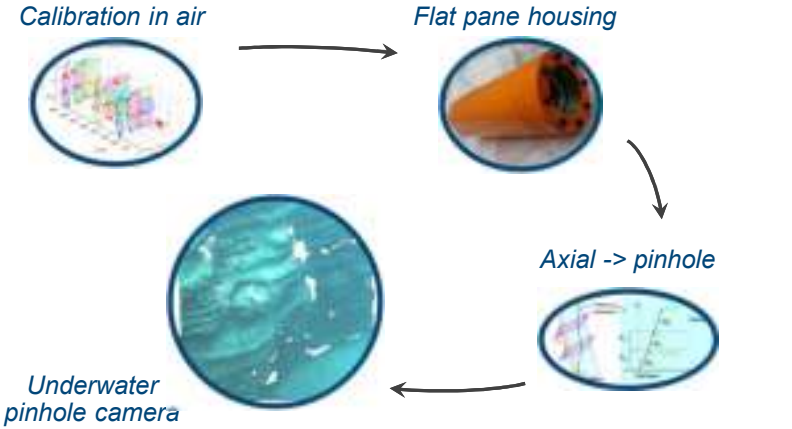
Pinax model for fast and accurate image rectification

Calibration in air → *Flat pane housing*

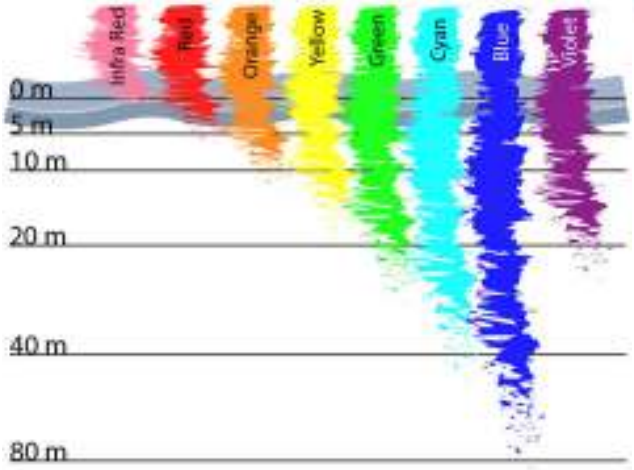
Pinax model for fast and accurate image rectification



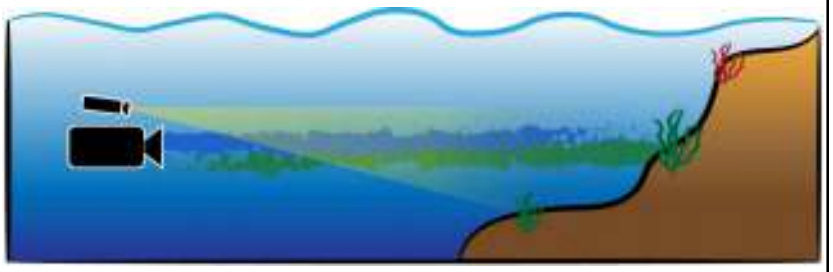
Pinax model for fast and accurate image rectification



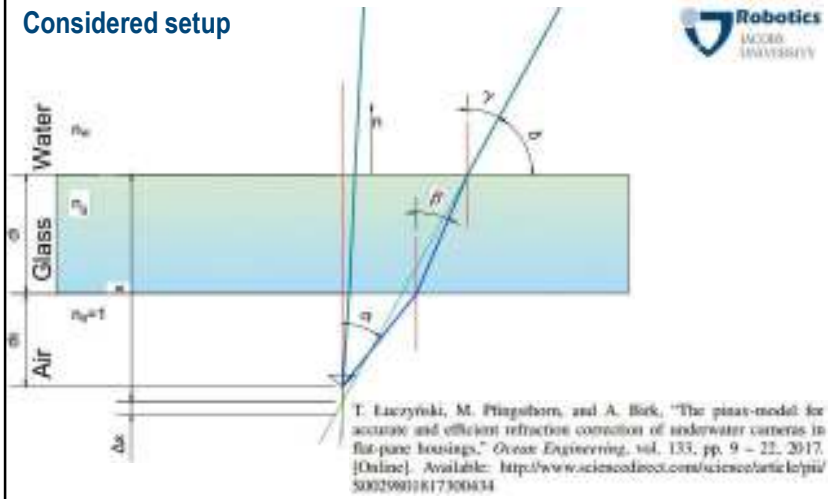
Underwater image formation model



Underwater image formation model

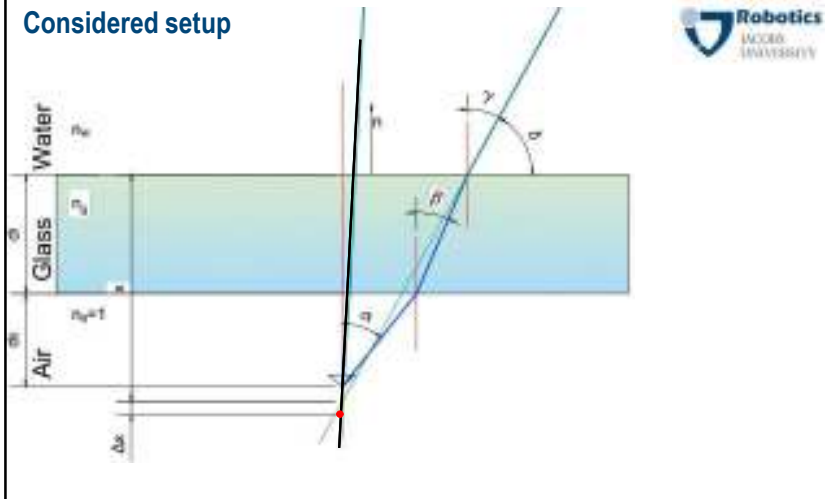


Considered setup

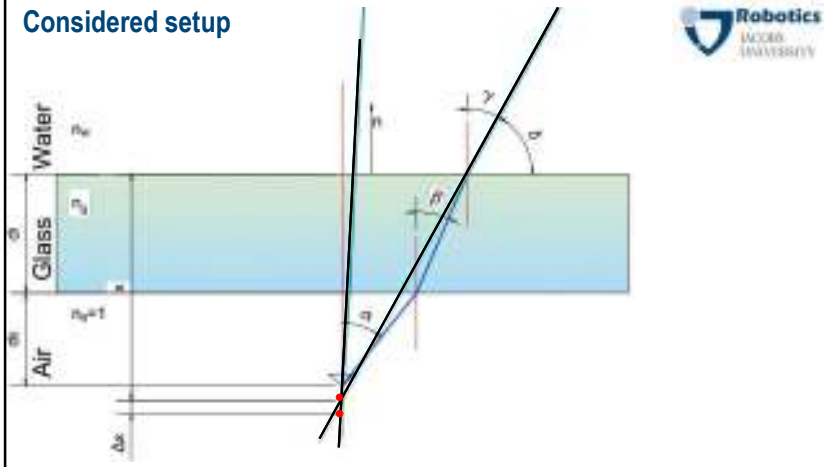


T. Łuczyński, M. Pfingsthorn, and A. Birk, "The pinax-model for accurate and efficient refraction correction of underwater cameras in flat-pane housings," *Ocean Engineering*, vol. 133, pp. 9 – 22, 2017. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0029801817300434

Considered setup



Considered setup



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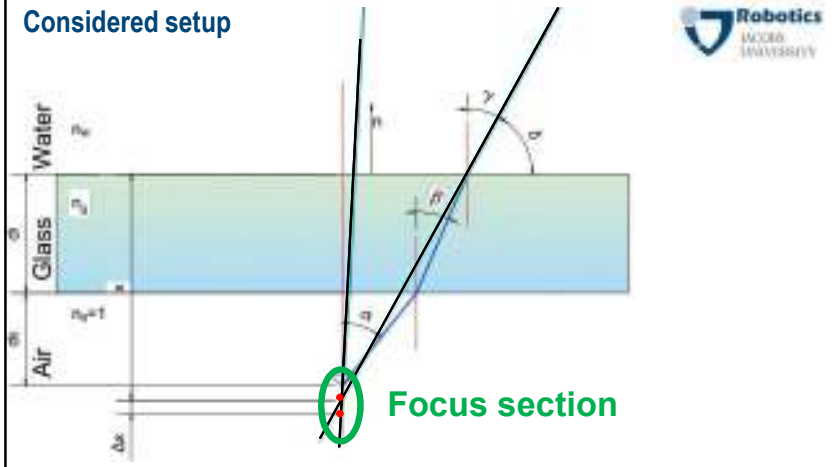
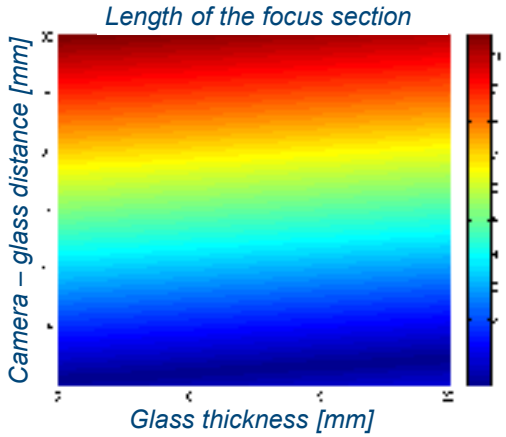


Influence of the camera distance to the glass panel



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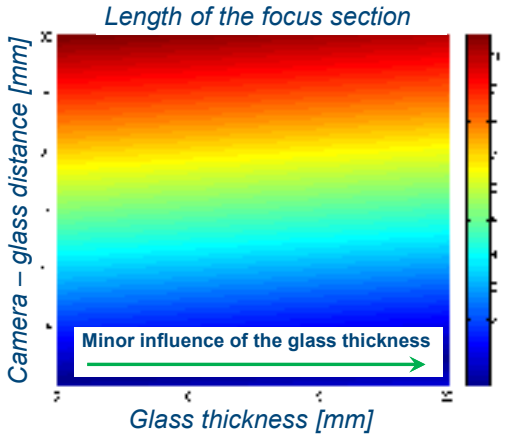

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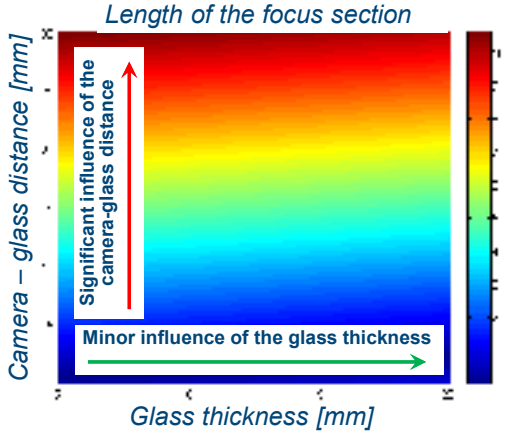

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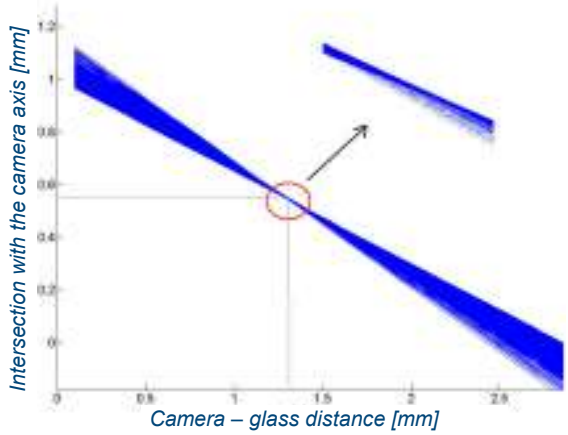

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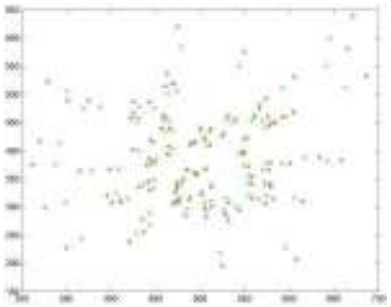

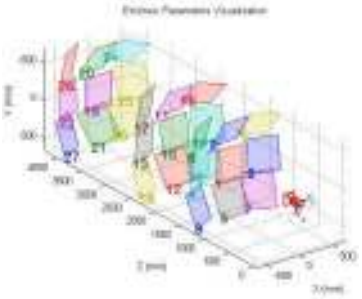

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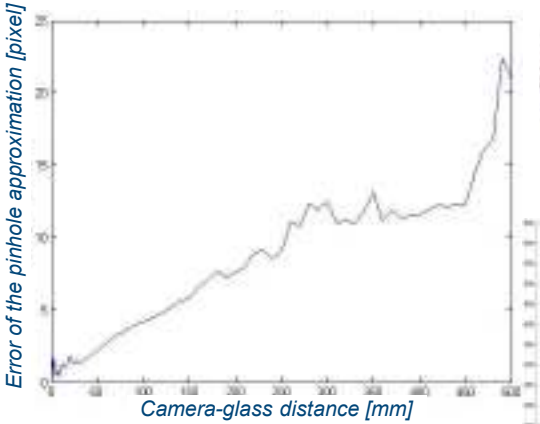
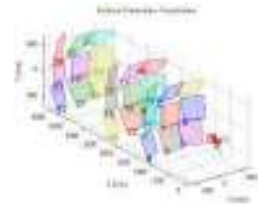
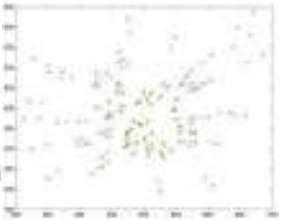
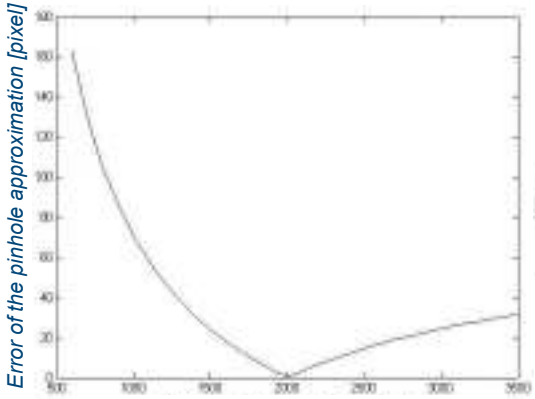
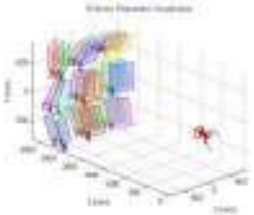




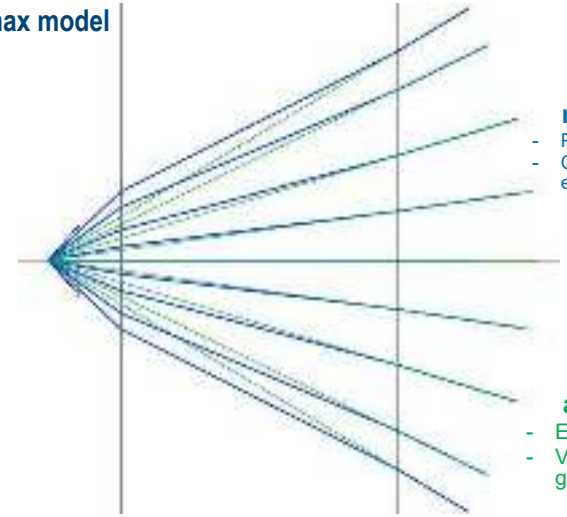


Special case: accuracy around the calibration distance





Pinax model



Accurate representation

- Physically correct
- Computationally expensive

Pinhole approximation

- Easy to use
- Valid for small camera-glass distance

Optimal camera positions

OPTIMAL $d_0^v/^v d_0^a$ OF THE CENTERS OF PROJECTION OF THE PHYSICAL/VIRTUAL CAMERA FOR DIFFERENT GLASS THICKNESSES AND SALINITY

d_1 [mm]	$n_w = 1.333$(sweet water)	$n_w = 1.342$(salty water)
1	0.15mm/0.06mm	0.14mm/0.06mm
3	0.45mm/0.18mm	0.42mm/0.17mm
5	0.76mm/0.31mm	0.70mm/0.29mm
10	1.52mm/0.61mm	1.40mm/0.58mm
15	2.28mm/0.92mm	2.10mm/0.87mm
20	3.04mm/1.22mm	2.80mm/1.15mm

Pinax model assumptions

- Small camera-glass distnace
- Camera axis perpendicular to the glass
- Known:
  - Glass thickness
  - Glass refraction index
  - ~ Water refraction index

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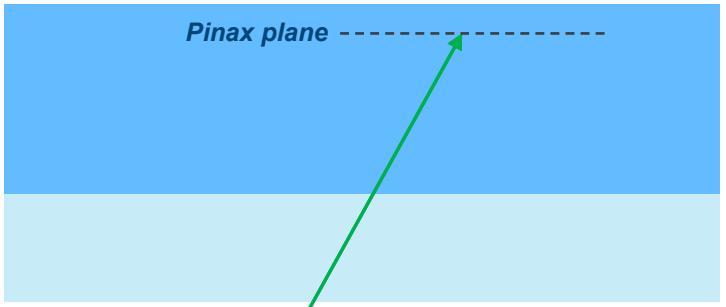
Correction map generation

Virtual, pinhole camera

Real camera (axial projection)

Correction map generation



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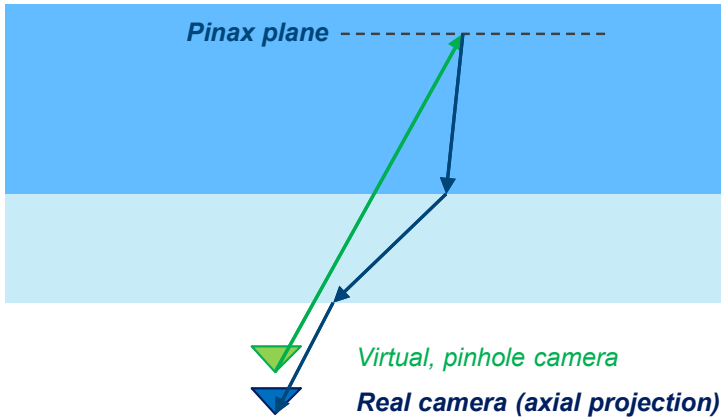
Real camera (axial projection)

Correction map generation

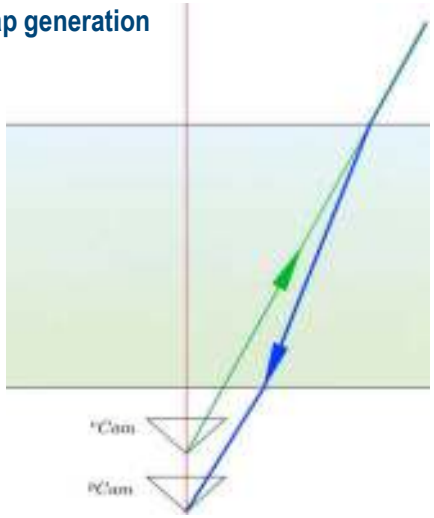


Correction map generation

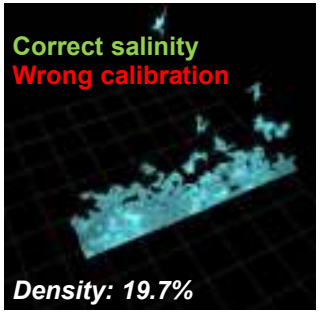
Map: pixel by pixel translation:
Registered image -> corrected image

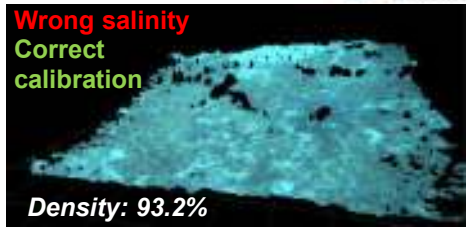
+ fast
+ precomputed
+ incorporates water properties

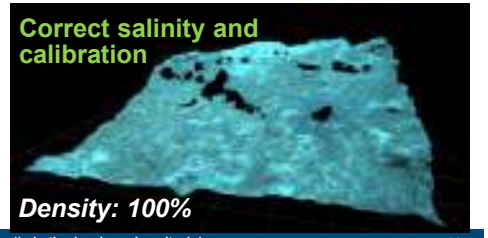
Correction map generation



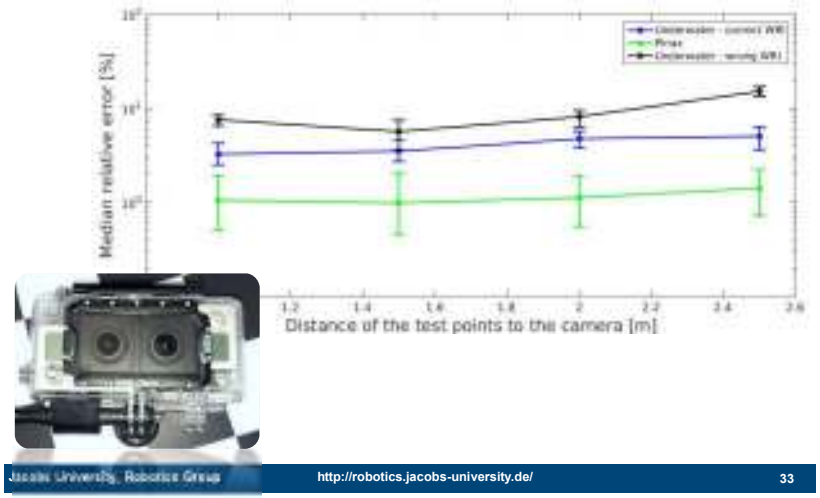
Influence of the salinity and calibration accuracy







Experimental evaluation



Pinax model assumptions

- Small camera-glass distnace
- Camera axis perpendicular to the glass
- Known:
  - Glass thickness
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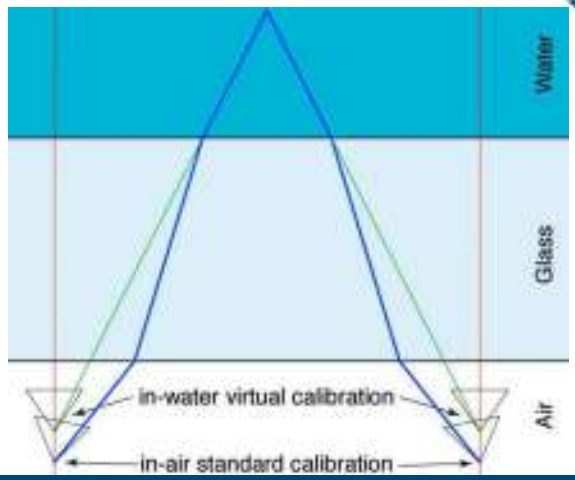
  - ~ Water refraction index

Pinax model assumptions

- Small camera-glass distnace
- **Camera axis perpendicular to the glass**
- Known:
  - Glass thickness
  - Glass refraction index
  - ~ Water refraction index

Pinax model for verged systems



Pinax model for verged systems

$$x = -\frac{t}{|t|}$$

$$a = \left[\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} + R \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \right] \cdot 0.5$$

$$z' = \frac{a}{|a|}$$

$$y = z' \times x$$

$$z = x \times y$$

$$R_{right} = (x, y, z)$$

$$R_{left} = R_{right} R^T$$

Pinax model for verged systems

$$x = -\frac{t}{|t|}$$

$$a = \left[\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} + R \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \right] \cdot 0.5$$

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$$y = z' \times x$$

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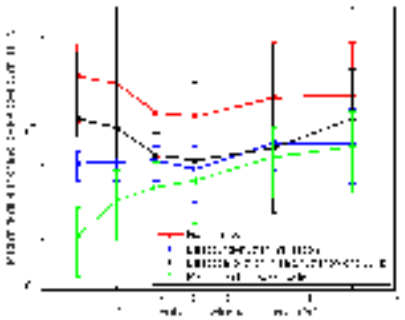
$$R_{left} = R_{right} R^T$$

~~Camera is axis perpendicular to the glass~~

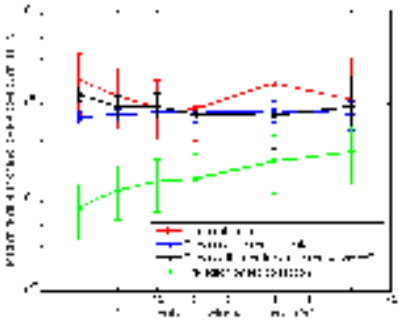
Baseline is parallel to the glass

Pinax model for verged systems

short



wide



Pinax model for verged systems

Questions?

https://github.com/tomluc/Pinax-camera-model

luczynski.tomek@gmail.com