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Investigation and modelling of rolling shutter distortions on photogrammetric single- and multi-image applications

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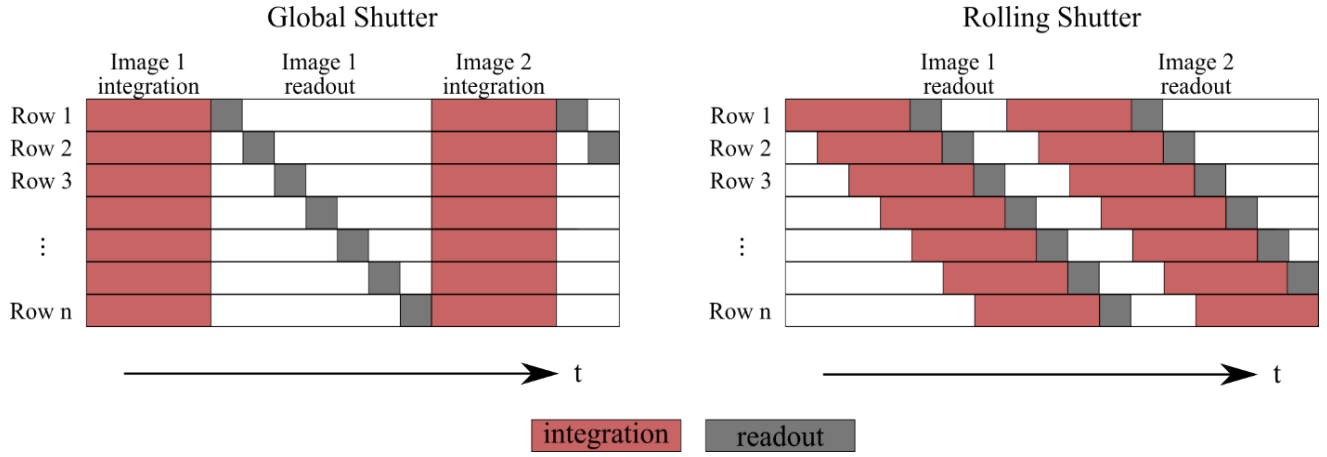
MOTIVATION

- Photogrammetry – „Information from imagery“
- Basic approach: Taking images that comply with the pinhole camera model
- CMOS technology is standard in many eligible cameras
  - (Usually) unable to save accumulated voltage
- Sensor is integrated and read out sequentially
  - → Exposure at many time intervals



according to Ringaby, 2012

- Causing distortions in kinematic applications
  - → Rolling shutter distortions

ROLLING SHUTTER DISTORTIONS

wikipedia.org, 2016a

wikipedia.org, 2016b

Magerand & Bartoli, 2010

(d)

Sun & Liu, 2012

MODEL

- Collinearity equations employ one exterior orientation per image (Global-Shutter-Model)

  → 6 degrees of freedom per image

$$\overrightarrow{X_T} = [X_0\ Y_0\ Z_0]^T \qquad \boldsymbol{R}(a, b, c, d)$$

- Rolling shutter creates one exterior orientation per image row

$$\overrightarrow{X_{T_1}} = [X_{0,1}\ Y_{0,1}\ Z_{0,1}]^T \qquad \boldsymbol{R_1}(a_1, b_1, c_1, d_1)$$
$$\overrightarrow{X_{T_2}} = [X_{0,2}\ Y_{0,2}\ Z_{0,2}]^T \qquad \boldsymbol{R_2}(a_2, b_2, c_2, d_2)$$
$$\vdots \qquad\qquad \vdots$$
$$\overrightarrow{X_{T_n}} = [X_{0,n}\ Y_{0,n}\ Z_{0,n}]^T \qquad \boldsymbol{R_n}(a_n, b_n, c_n, d_n)$$

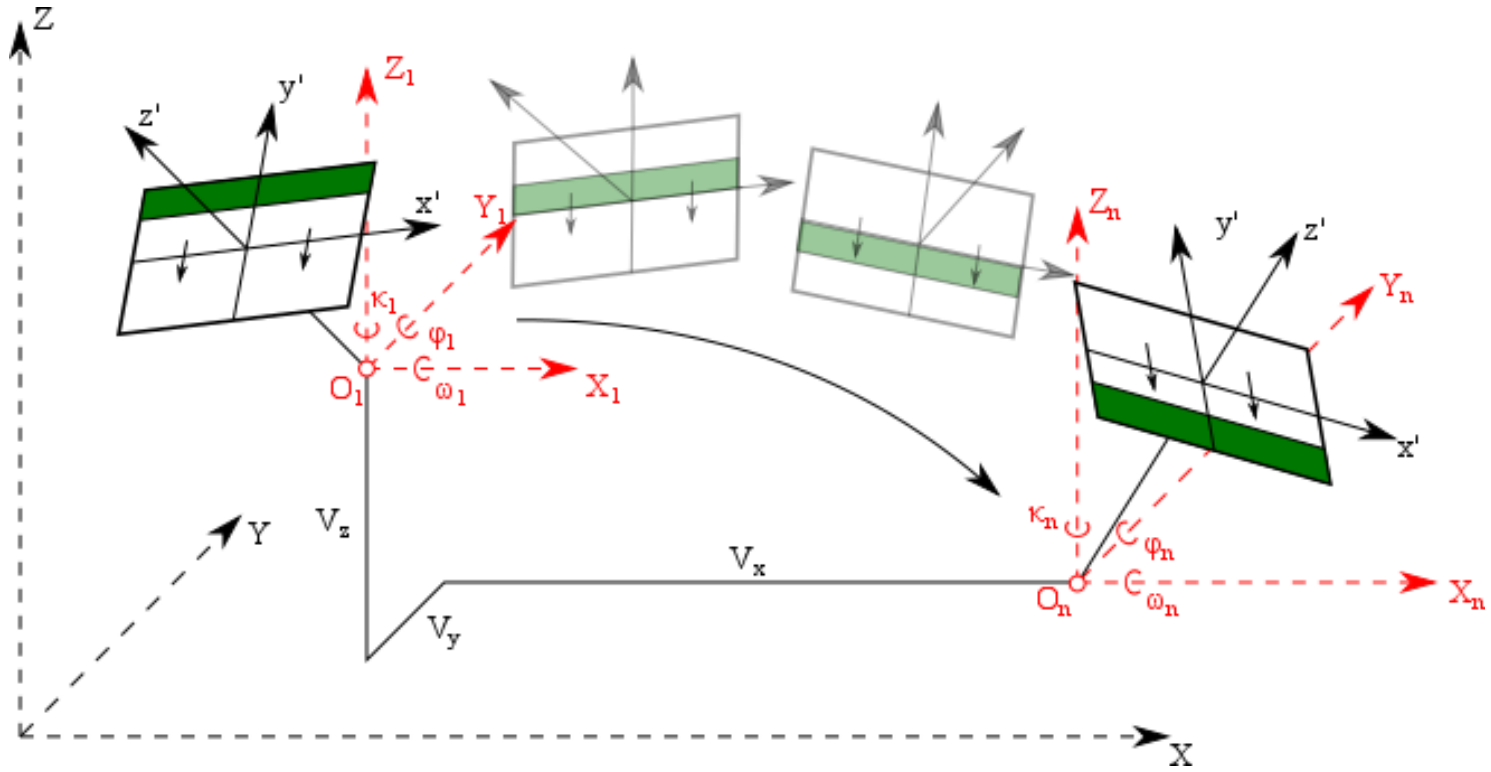
  → 6 degrees of freedom per row → 6n degrees of freedom per image

- Problem: High amount of unknowns causes an underdetermined system of equations

- Solution: Restriction to two exterior orientations and interpolation

$$\overrightarrow{X_{0_1}} = \left[X_{0,1}\ Y_{0,1}\ Z_{0,1}\right]^T \qquad \boldsymbol{R_1}(a_1, b_1, c_1, d_1)$$

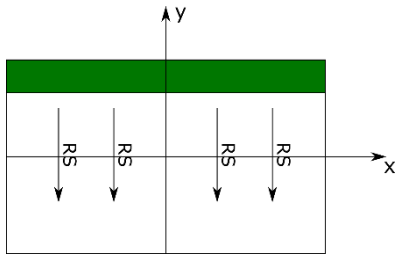
$$\overrightarrow{X_{0_n}} = \left[X_{0,n}\ Y_{0,n}\ Z_{0,n}\right]^T = \overrightarrow{X_{0_1}} + \overrightarrow{V} \qquad \boldsymbol{R_n}(a_n, b_n, c_n, d_n)$$



- Collinearity equations for Rolling Shutter
  - Additional variables
    - V → Translation during image acquisition
    - q_1, q_n → Unit quaternions for rotation
      → R_{int}: Interpolated rotation matrix, dependent on τ
    - τ → Normalized interpolation factor, dependent on y‘
  - 12 degrees of freedom → Min. 6 spatially distributed points

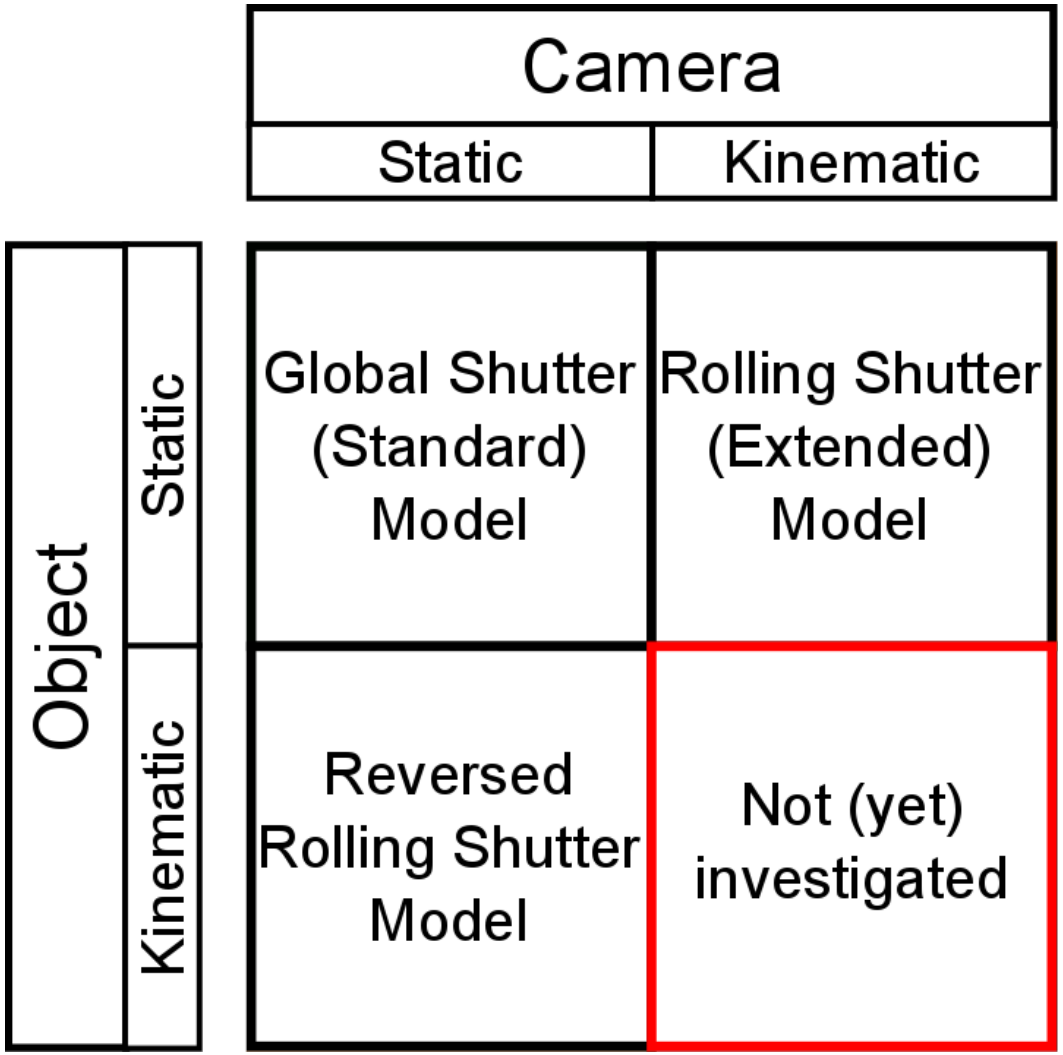
$$x' = x'_0 + z' \frac{r_{int}(\tau)_{11}(X - (X_0 + \tau V_x)) + r_{int}(\tau)_{21}(Y - (Y_0 + \tau V_y)) + r_{int}(\tau)_{31}(Z - (Z_0 + \tau V_z))}{r_{int}(\tau)_{13}(X - (X_0 + \tau V_x)) + r_{int}(\tau)_{23}(Y - (Y_0 + \tau V_y)) + r_{int}(\tau)_{33}(Z - (Z_0 + \tau V_z))} + \Delta x'$$

$$y' = y'_0 + z' \frac{r_{int}(\tau)_{12}(X - (X_0 + \tau V_x)) + r_{int}(\tau)_{22}(Y - (Y_0 + \tau V_y)) + r_{int}(\tau)_{32}(Z - (Z_0 + \tau V_z))}{r_{int}(\tau)_{13}(X - (X_0 + \tau V_x)) + r_{int}(\tau)_{23}(Y - (Y_0 + \tau V_y)) + r_{int}(\tau)_{33}(Z - (Z_0 + \tau V_z))} + \Delta y'$$

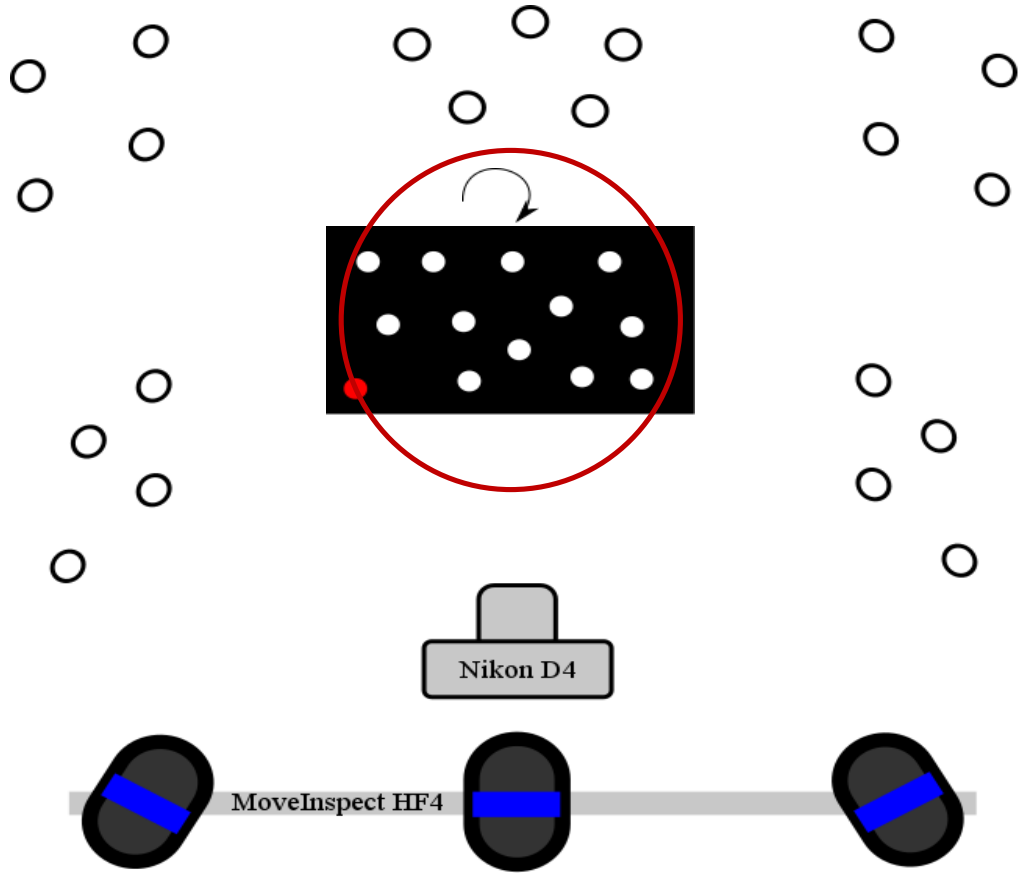


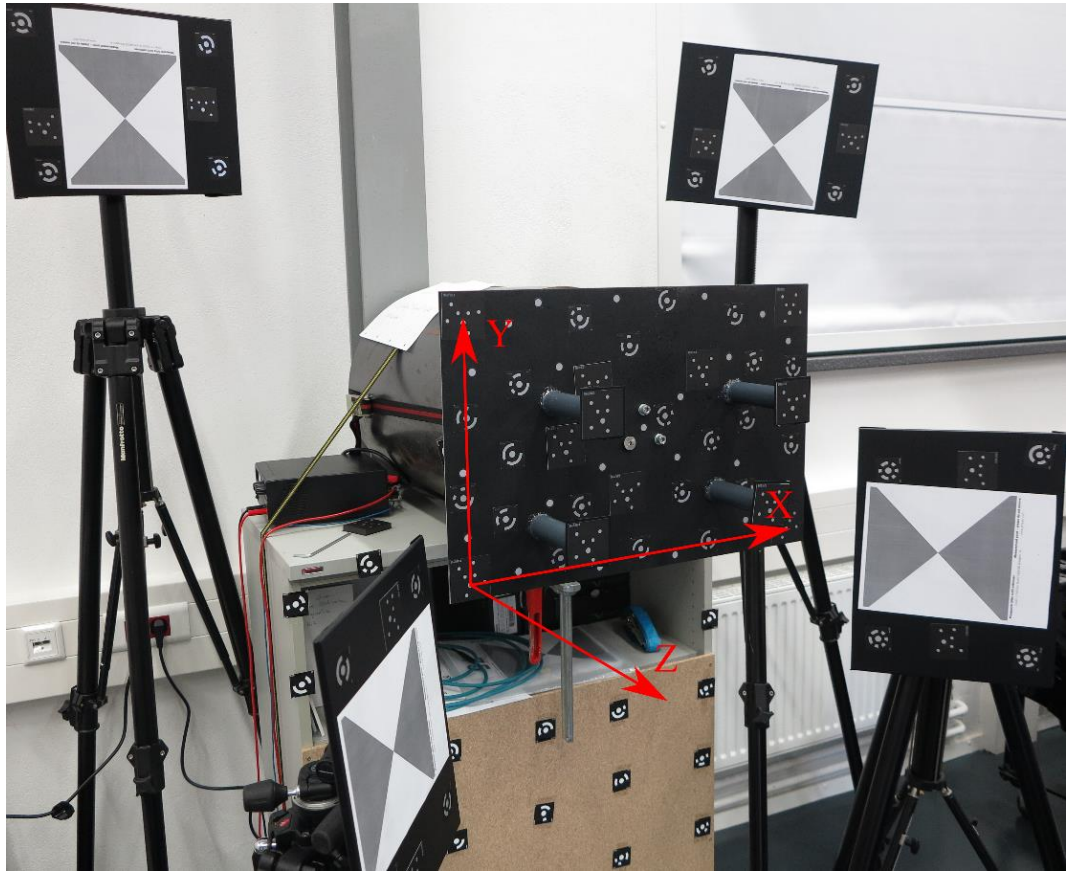
$$\tau = \frac{y_{max} - y'_i}{y_{max} - y_{min}}$$

COVERED SCENARIOS

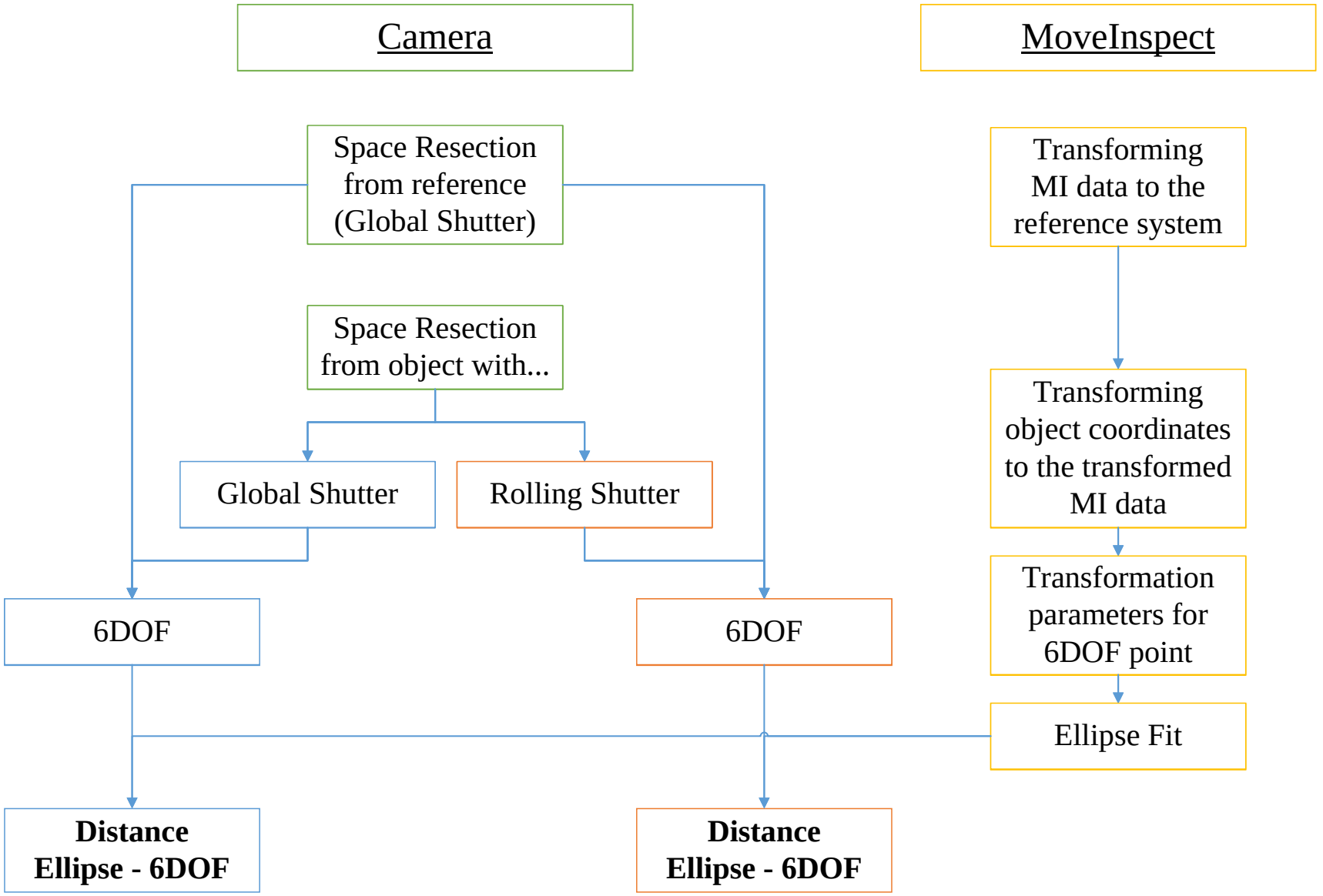


EXPERIMENTAL CONFIGURATION

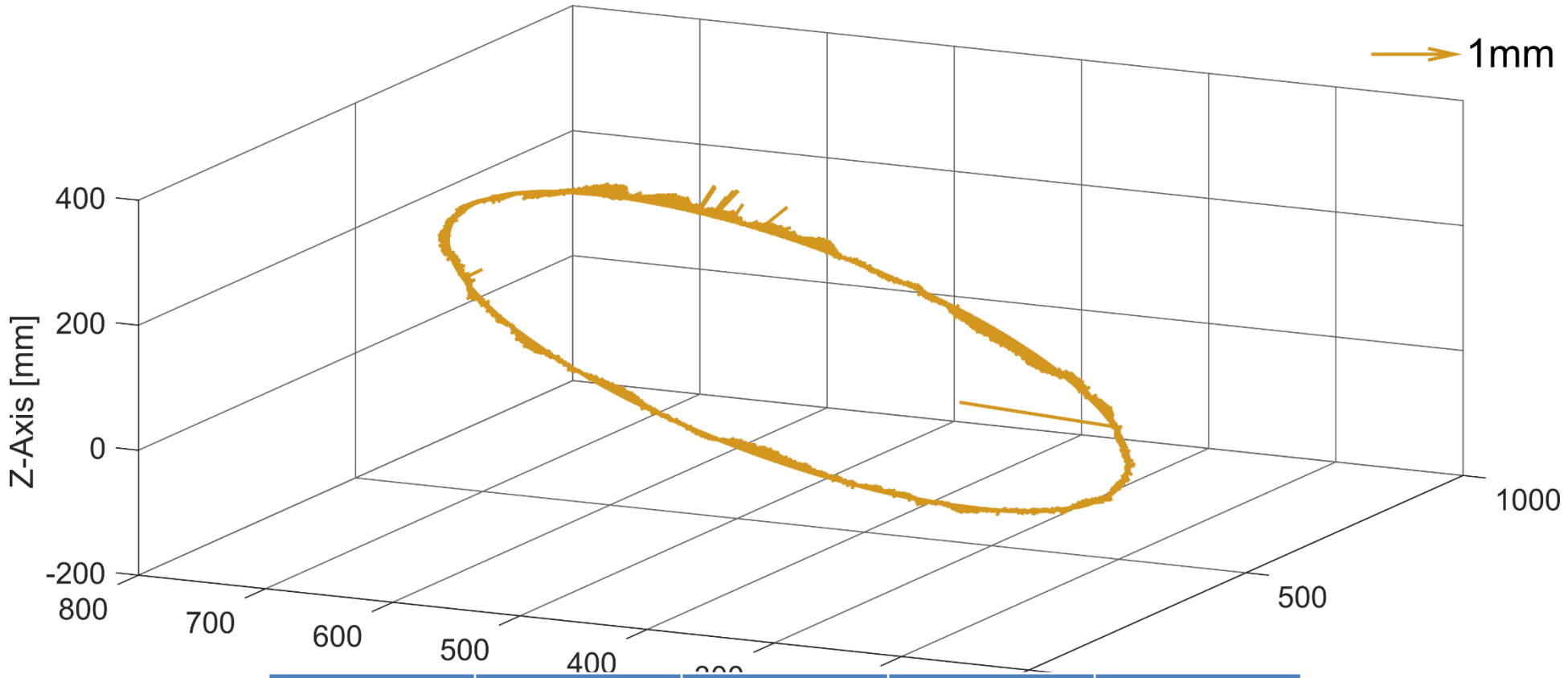




SINGLE IMAGE ANALYSIS

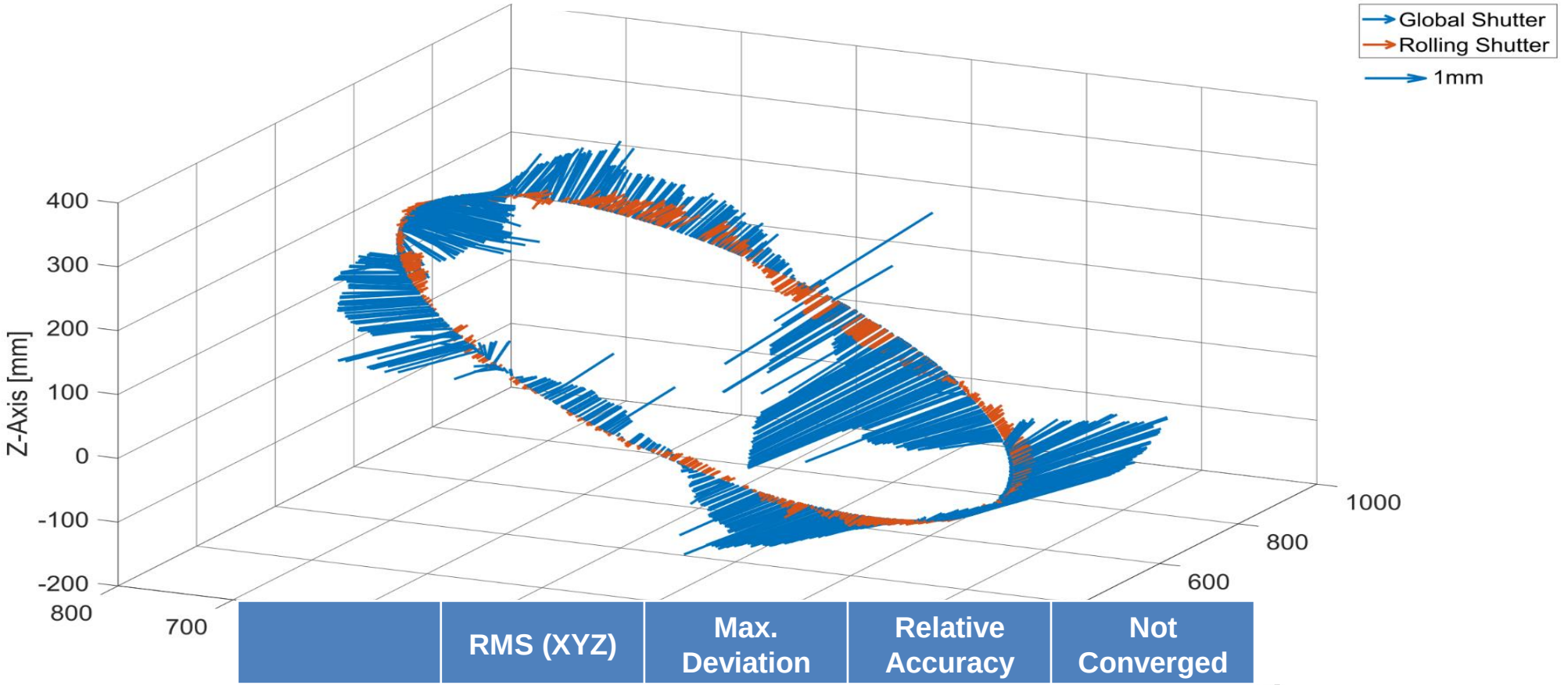


ELLIPSE FIT MI DATA - RESIDUALS



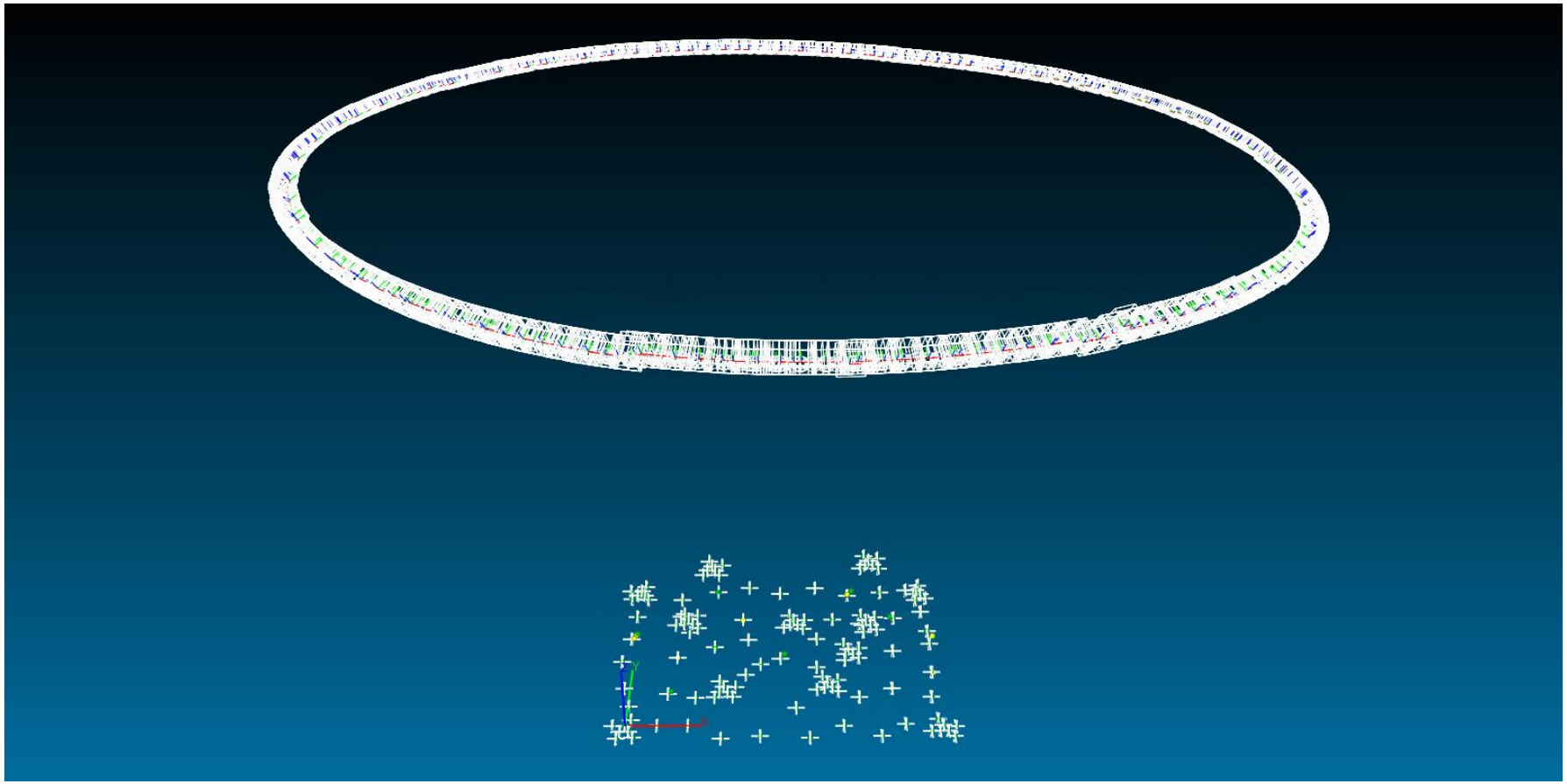
Standard Deviation	X	Y	Z	XYZ
Ellipse	0.031 mm	0.072 mm	0.079 mm	0.111 mm

SINGLE IMAGE ANALYSIS - RESULTS

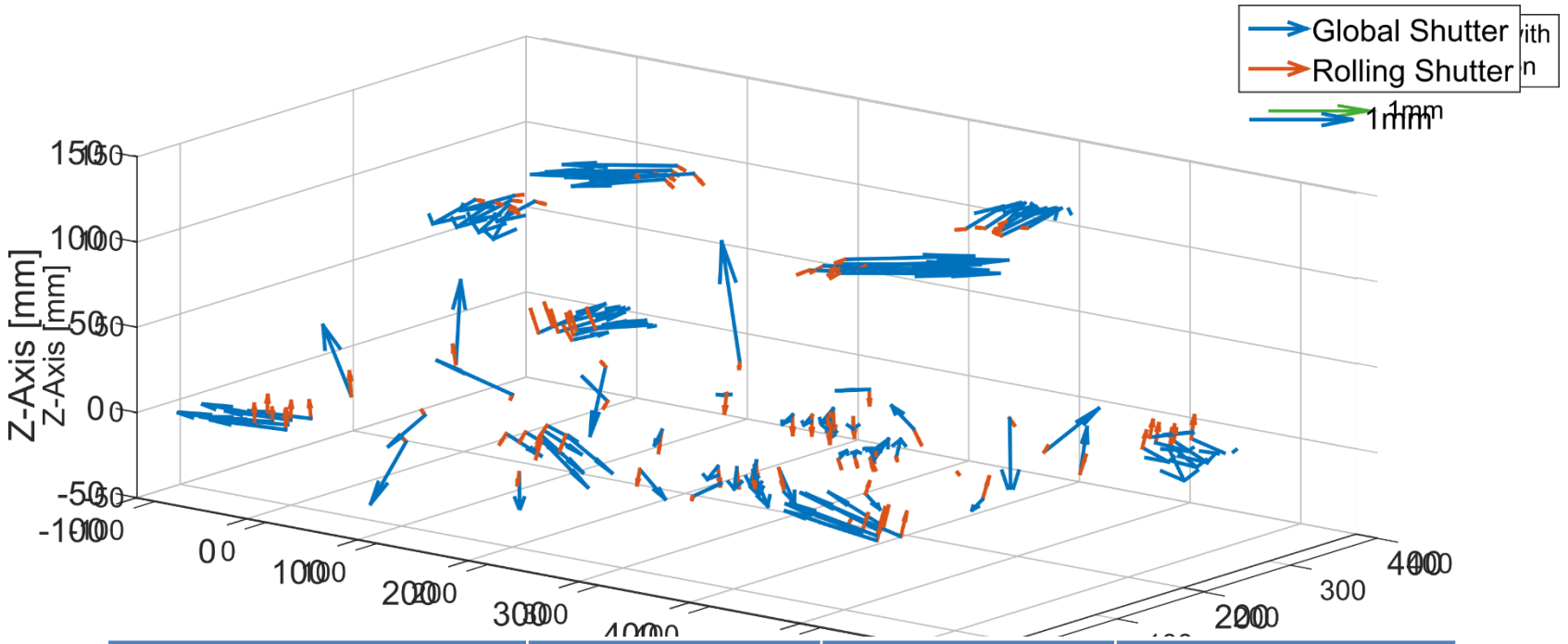


	RMS (XYZ)	Max. Deviation	Relative Accuracy	Not Converged
Global Shutter	1.302 mm	6.072 mm	1:260	0.0 %
Rolling Shutter	0.246 mm	0.920 mm	1:1715	2.7 %

MULTI IMAGE ANALYSIS



BUNDLE ADJUSTMENT - RESULTS

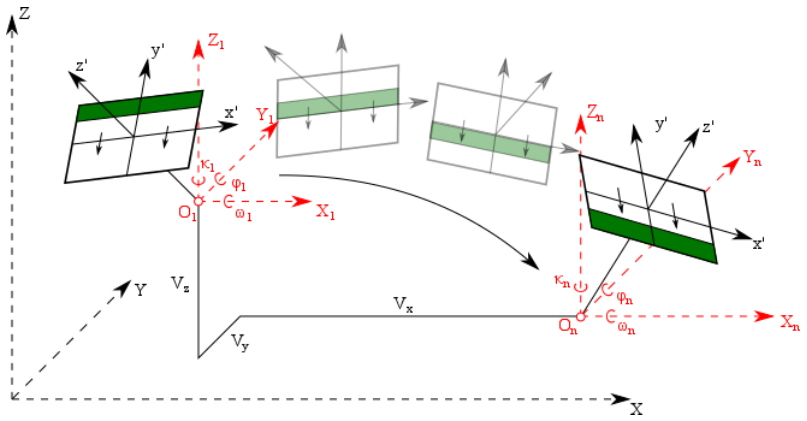


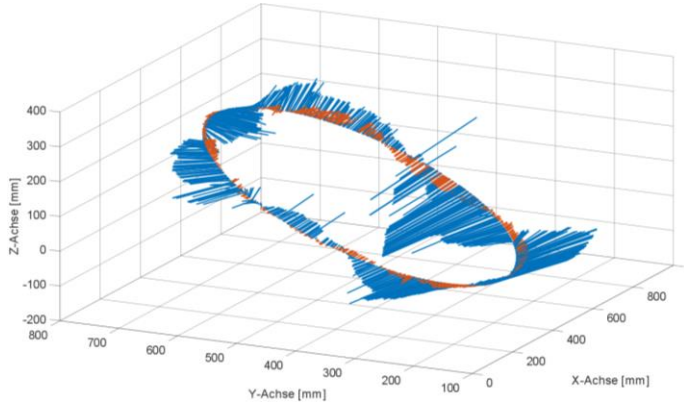
	RMS (XYZ)	Max. Deviation	Relative Accuracy
Global Shutter	0.864 mm	1.910 mm	1:383
Rolling Shutter	0.101 mm	0.183 mm	1:3992
Rolling Shutter with GS-approximation	0.490 mm	1.139 mm	1:642

CONCLUSION AND OUTLOOK

- The model describes the real conditions
  - Accuracy improvement > factor 5
- Parameters of exterior orientation(s) are highly correlated
  - Singular systems of equations
  - Inaccurate parameter estimation
    - → Depth is crucial for a robust estimation
    - → Approximate values have high impact on the results of a bundle adjustment

- Outlook
  - Improvement of approximate values/robustness
  - Influence on image measurements
  - Precorrect distorted image for Global Shutter analysis
  - High-speed applications for low cost cameras





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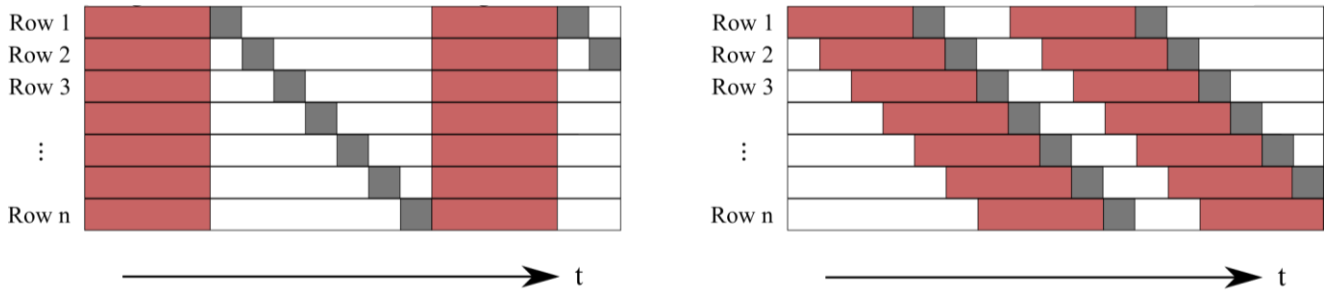

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