A Linear Positioning System for Light Field Capture

Suren Vagharshakyan, Olli Suominen, Ahmed Durmush,
Robert Bregović, Atanas Gotchev

Centre for Immersive Visual Technologies, Tampere University of Technology, Finland

TAMPERE UNIVERSITY OF TECHNOLOGY

european training network on full parallax imaging

CIVIT

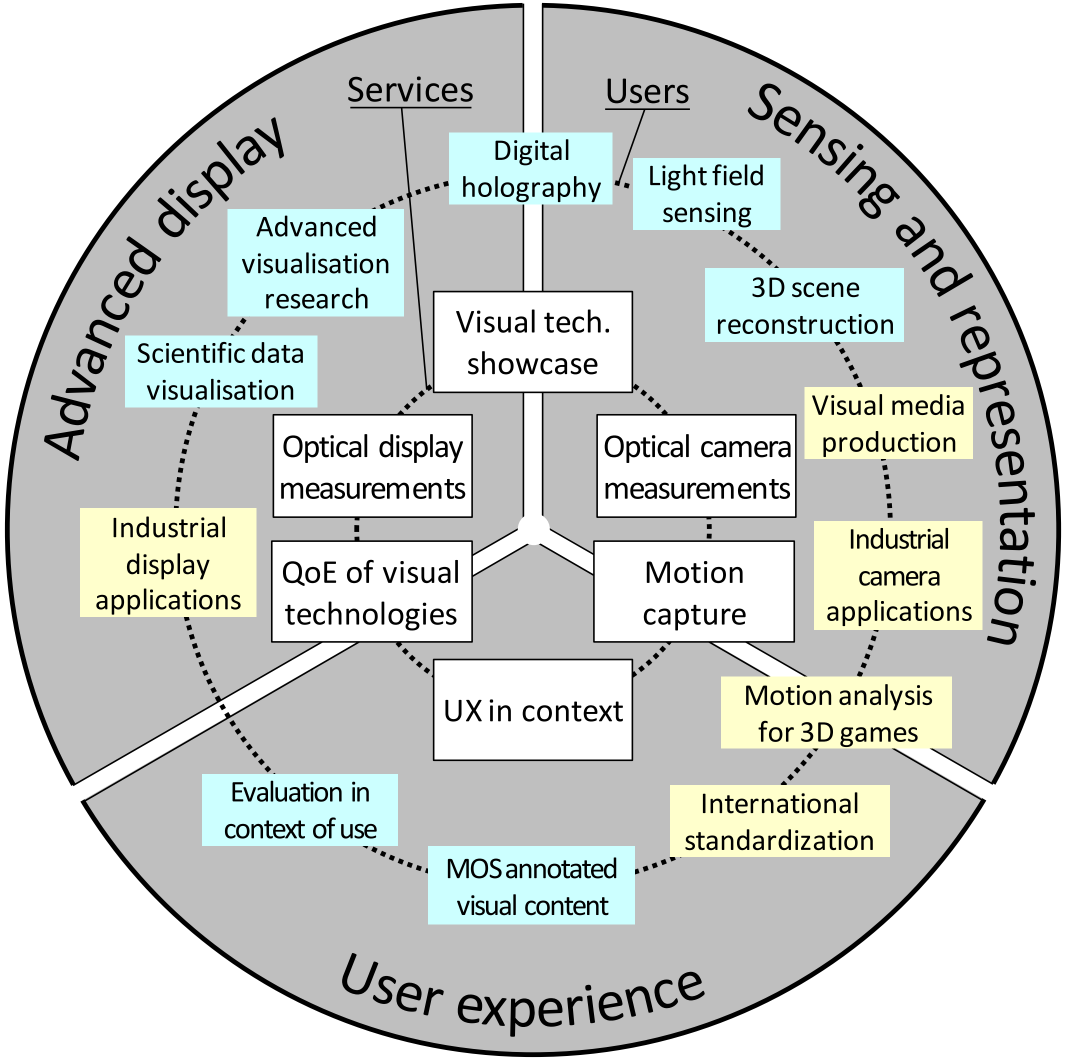
Centre for Immersive Visual Technologies (CIVIT)

Three sectors of equipment, data and expertise

Addressed challenges

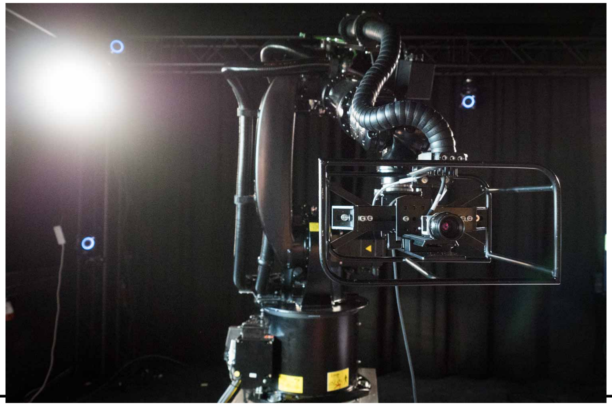
- New means for scene sensing for creating rich visual content
- Computational methods and computing platforms for dealing with data complexity
- Studying the user experience of novel visual technologies

Three sectors



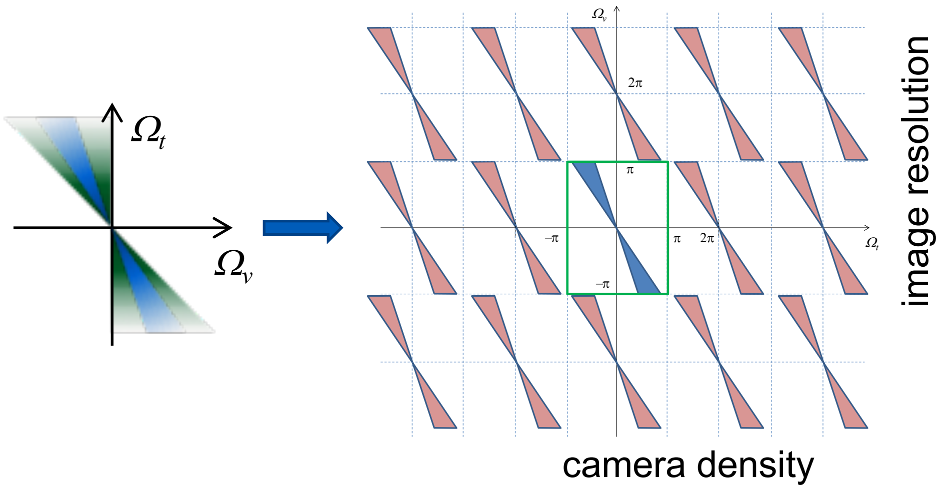
Sensing

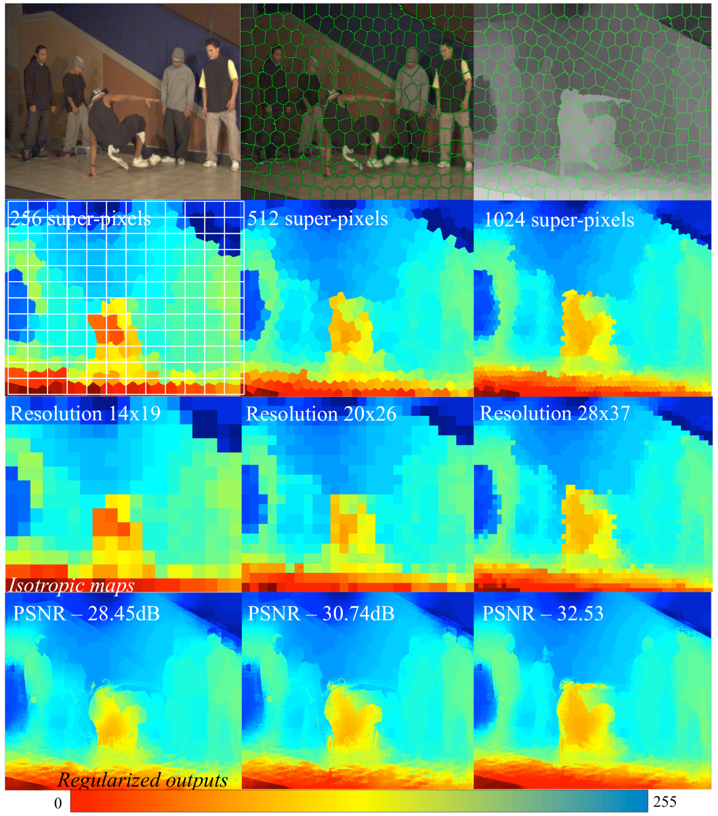
- Multiple camera systems
- Active and passive range sensors
- Motion capture
- Equipment concentrated in the CIVIT capture studio



Representation

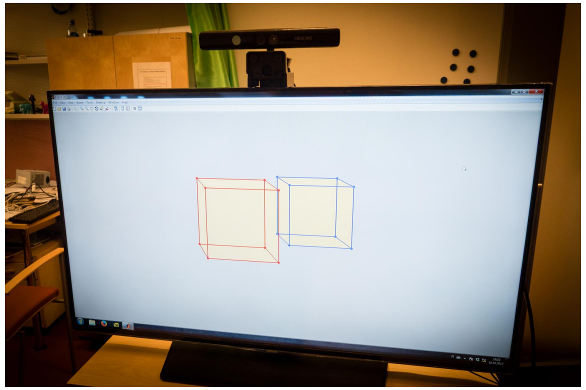
- Milti-view multi-depth
- Light field
- Holographic

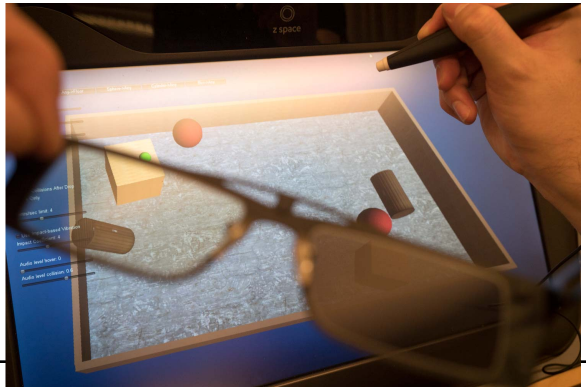




Displays

- Ultra-high definition
- High-dynamic range
- Stereoscopic and multi-view
- VR
- Light-field
- Holographic prototypes
- Equipment concentrated in the CIVIT VR studio



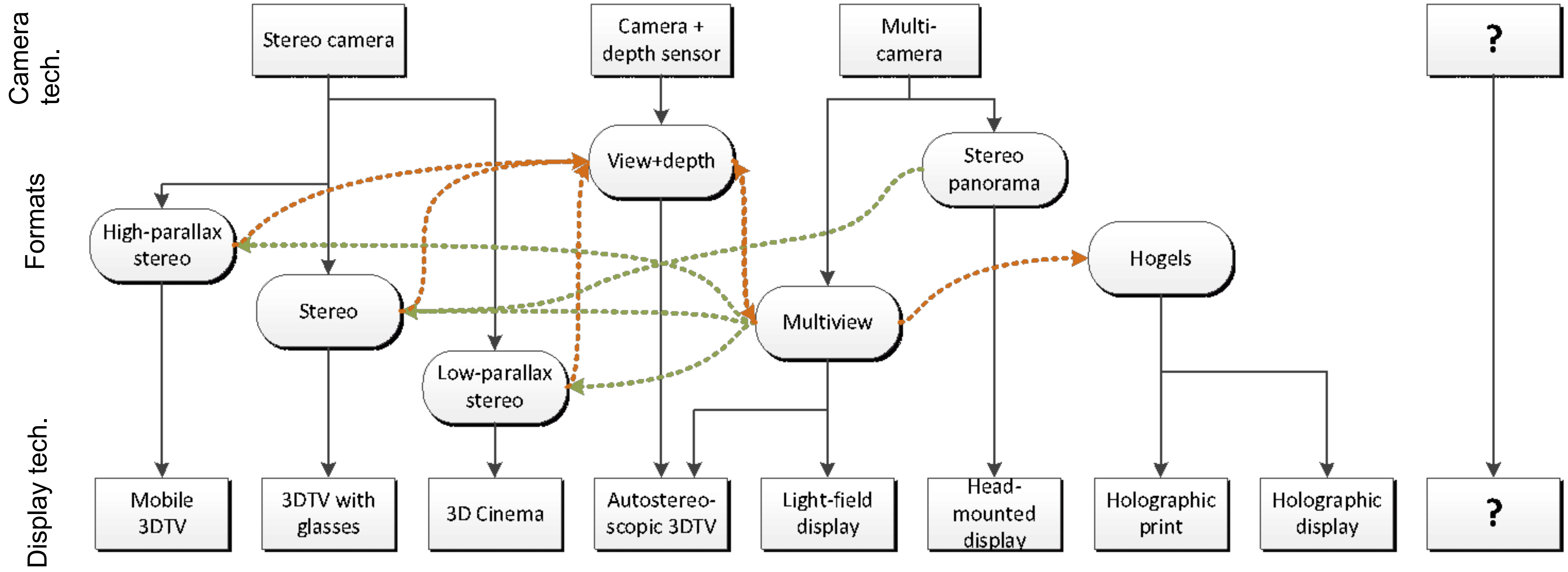


User experience

- Indoor testing lab
- Mobile testing lab
- Equipment concentrated in the CIVIT UX studio (under construction)

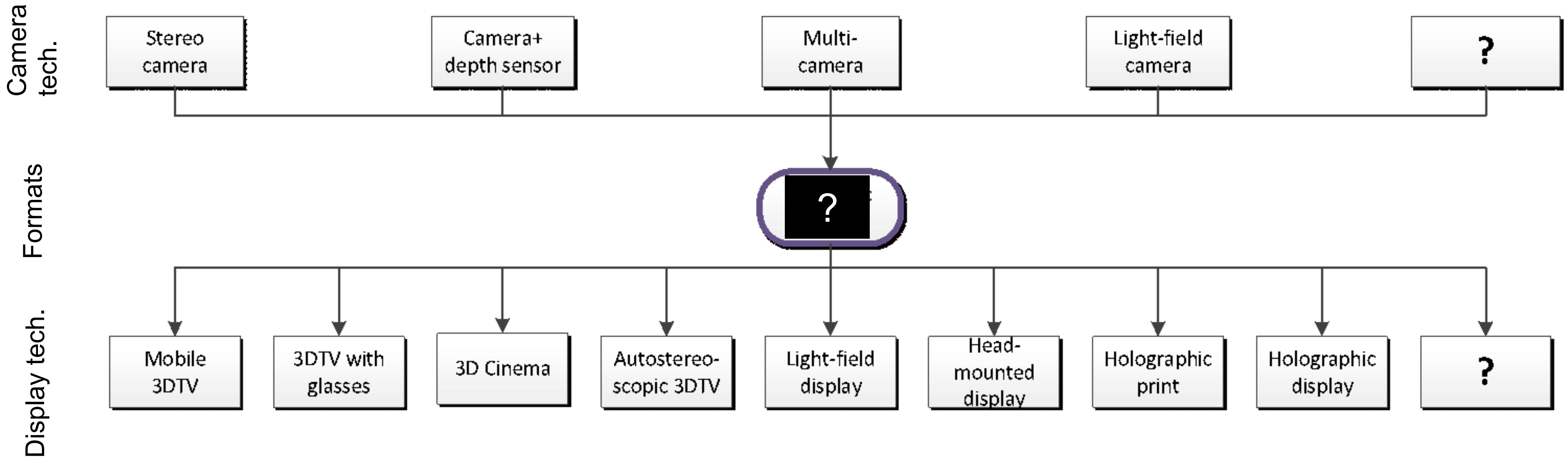
Outcomes

- Fundamental understanding of data, representation and conversion



Outcomes

- Fundamental understanding of data, representation and conversion

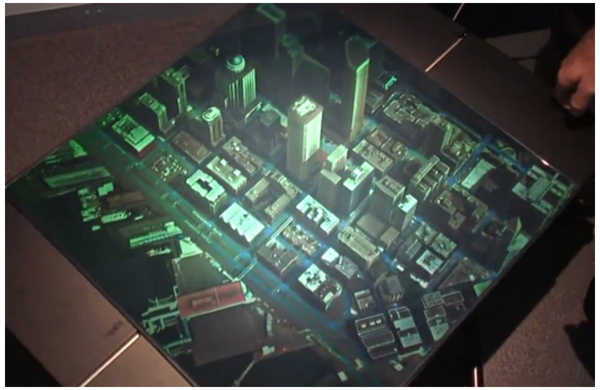


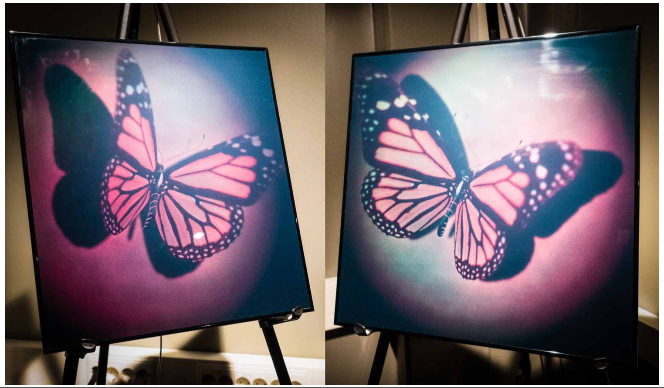
Outcomes

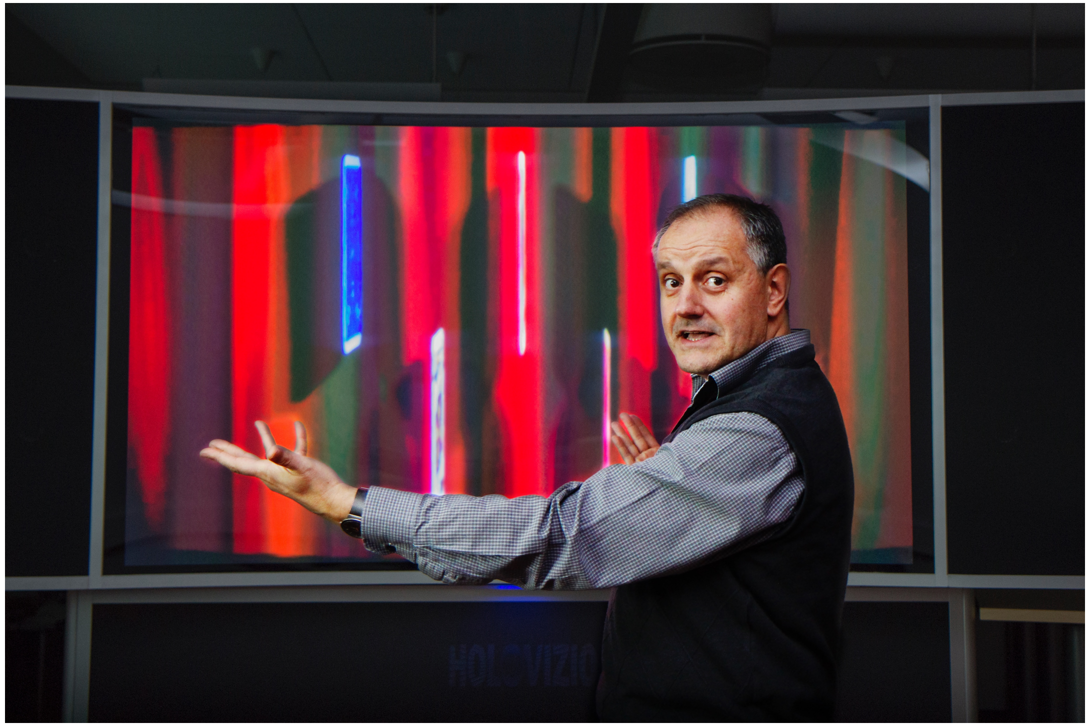
- Sensing
  - Multi-sensor, online and real-time processing
- Displays
  - Ultimate goal: create means for full-parallax 3D visualization

Motivation for setting up a linear positioning system

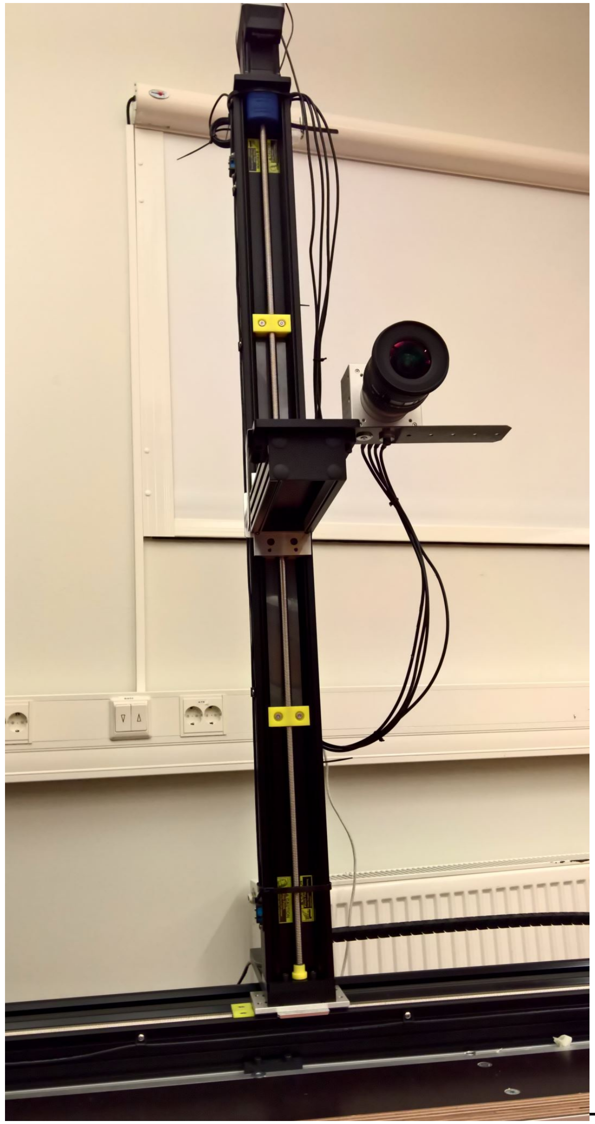
- Capture densely sampled light fields to serve visualizations such as
  - Holographic stereograms
  - Wide Field-of-View light field displays

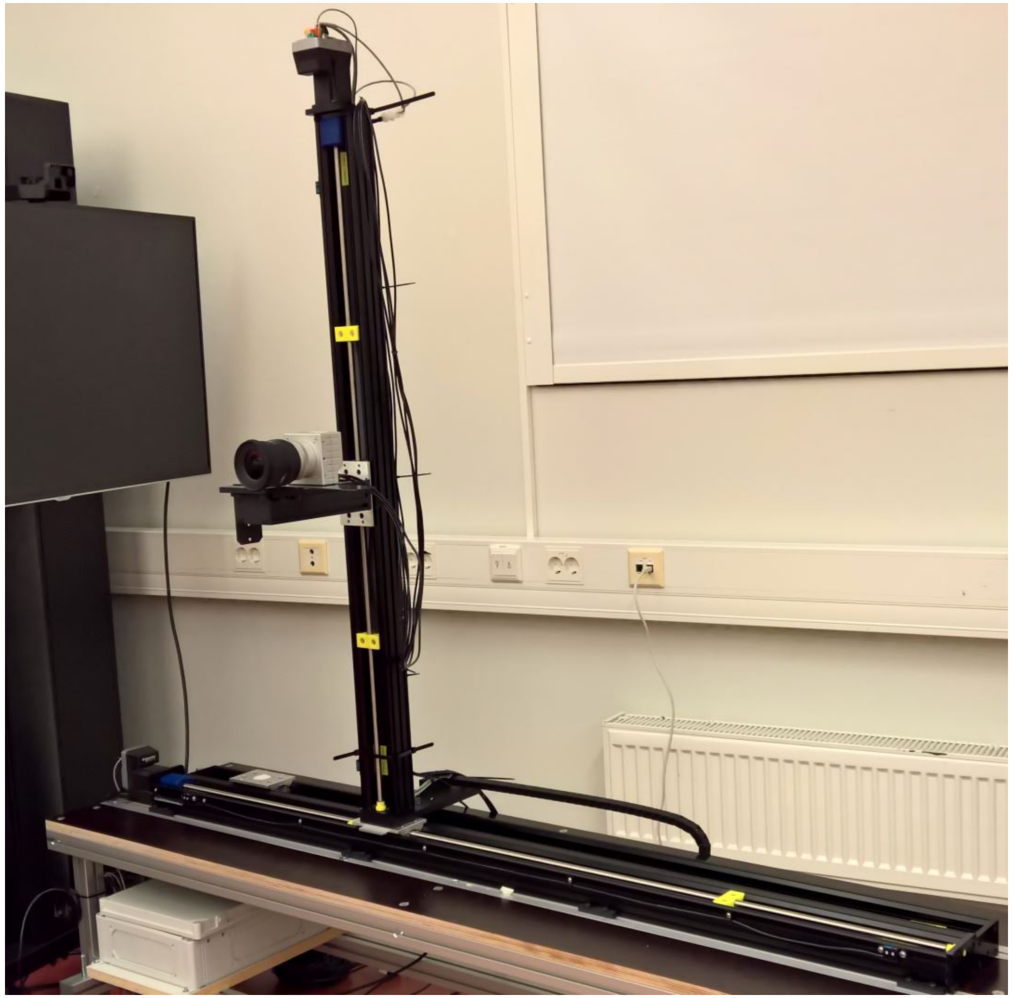






Linear positioning system





Accuracy	±20μm
Precision (Repeatability)	4μm
Straight Line Accuracy	38μm
Maximum Linear Speed	20 mm/s
Maximum Payload	20 kg
X Axis Travel Distance	1524mm
Y Axis Travel Distance	1016mm

Linear positioning system

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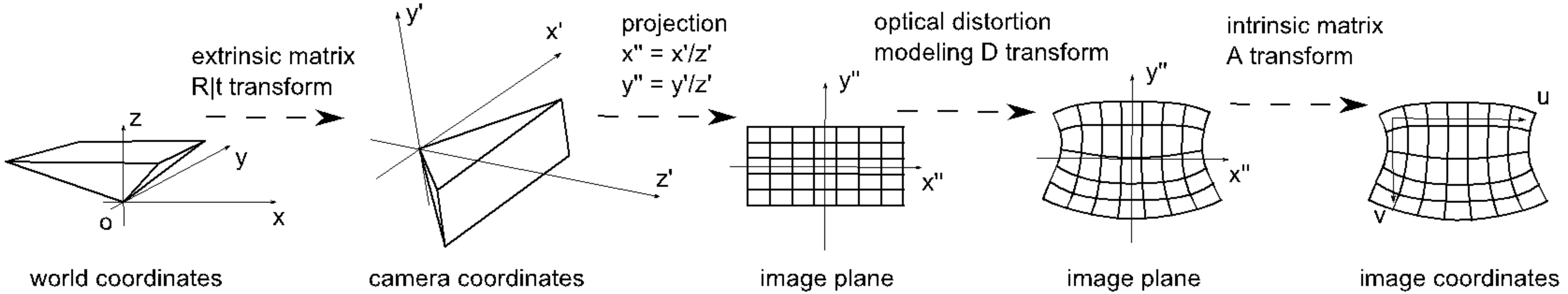
Pinhole camera with optical distortions

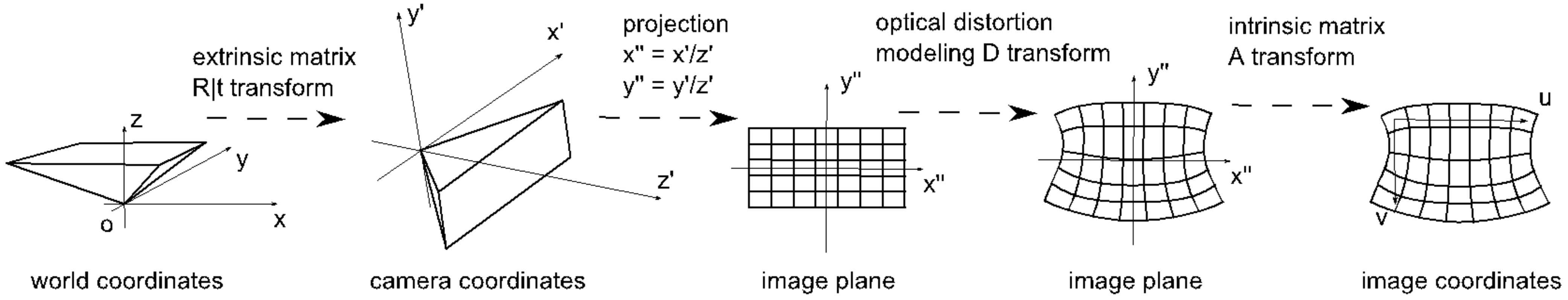


Pinhole camera projection model

$$sm = A[R|t]M$$

$$m = \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}, A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}, R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}, t = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix}, M = \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Pinhole camera with optical distortions



Optical distortion model

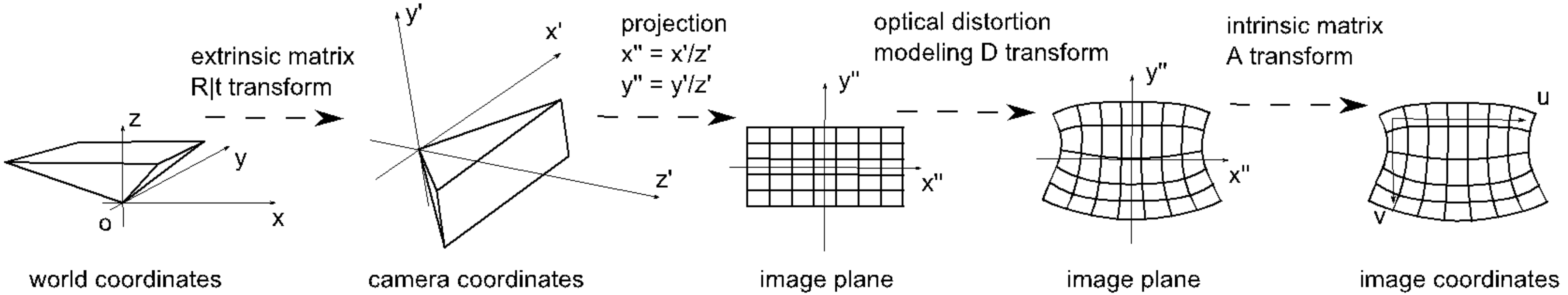
$$x^* = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1 xy + p_2(r^2 + 2x^2)$$

$$y^* = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2y^2) + 2p_2 xy$$

$$r = \sqrt{x^2 + y^2}$$

k_1, k_2, k_3 Radial distortion coefficients
t_1, t_2 Tangential distortion coefficients

Pinhole camera with optical distortions



$$\begin{bmatrix} u \\ v \end{bmatrix} = F_{R,t,I}\left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}\right)$$

Common projection model
R – 3D rotation matrix
t – 3D position
I – optical distortion coefficients

Single camera parameters estimation

$$\underset{R,t,I}{\operatorname{argmin}} \sum_{k=1}^{N} \left\| F_{R,t,I}(M_k) - m_k \right\|^2$$

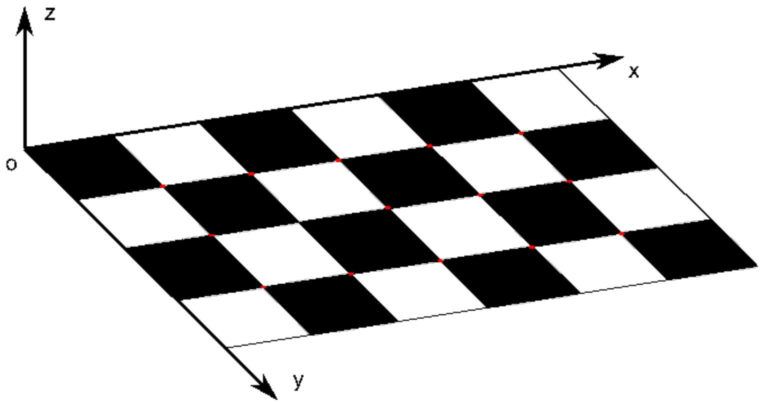
Inverse problem:
For given set of 3D points $M_k = \begin{bmatrix} x_k \\ y_k \\ z_k \end{bmatrix}, k = 1, \ldots, N$

and their corresponding projections $m_k = \begin{bmatrix} u_k \\ v_k \end{bmatrix}, k = 1, \ldots, N$

Estimate camera parameters R, t, I

Minimization solved based on Levenberg-Marquard
Implementation provided in *OpenCV* Library

Measurements

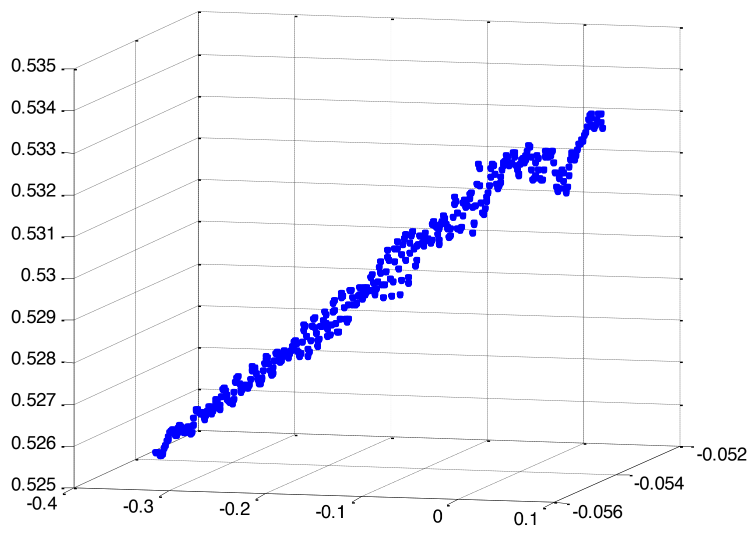


$$M_k = \begin{bmatrix} x_k \\ y_k \\ z_k \end{bmatrix}, k = 1, \dots, N$$

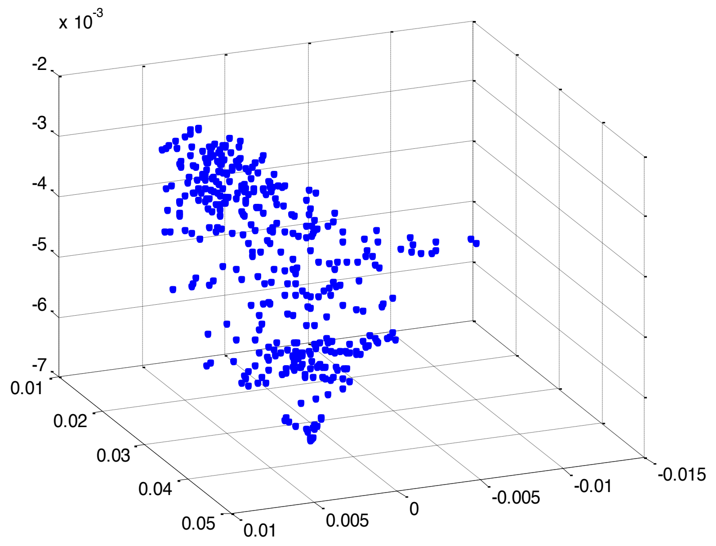
$$m_k = \begin{bmatrix} u_k \\ v_k \end{bmatrix}, k = 1, \dots, N$$

Set of captured images with chessboard

Camera positions and rotation estimation with common optical distortions

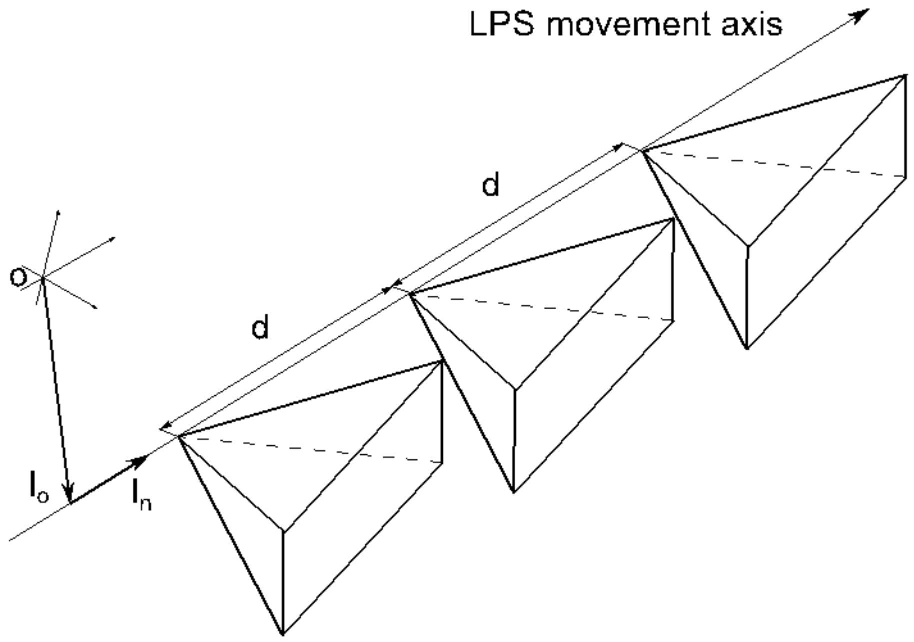


Position in millimeters



Rotation in radians

Camera locations constraints



$$t_i = l_0 + (id)l_n, \qquad i = 1, \ldots, K$$

Set of cameras positioned over the line, with common rotation and common lens distorition model

Multi-camera parameters estimation with constraints

$$\underset{R,l_0,l_n}{\operatorname{argmin}} \sum_{i=1}^{K} \sum_{k=1}^{N} \left\| F_{R,l_0+d_i l_n,I^*}(M_k) - m_{k,i} \right\|^2$$

K-number of images (~400)
N-number of chessboard inner points (8 by 4)

Multi-camera parameters estimation with constraints

$$\underset{R,l_0,l_n}{\operatorname{argmin}} \sum_{i=1}^{K} \sum_{k=1}^{N} \left\| F_{R,l_0+d_i l_n,I^*}(M_k) - m_{k,i} \right\|^2$$

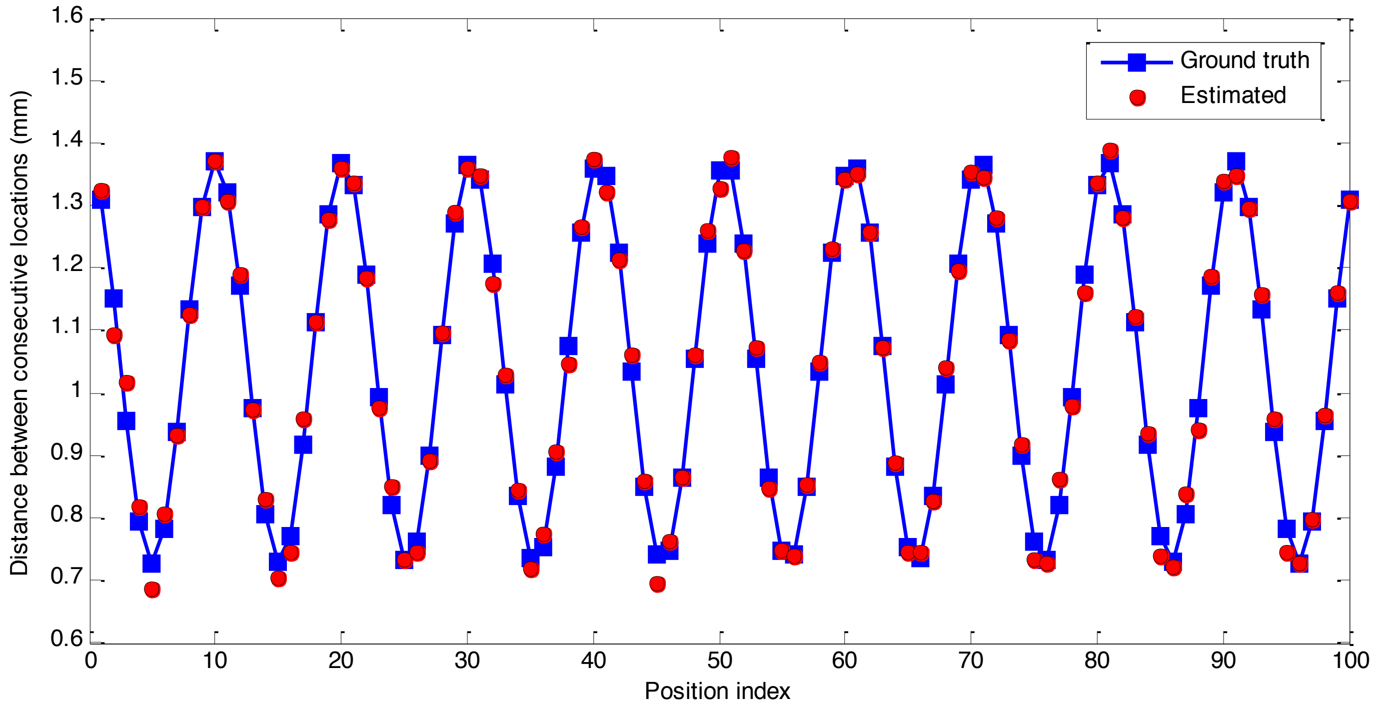
$$\underset{R,l_0,l_n}{\operatorname{argmin}} \sum_{i=1}^{K} \sum_{k=1}^{N} \left\| F_{R,l_0+d_i l_n,I^*}(M_k) - m_{k,i} \right\|^2$$

Estimate common rotation and movement line in 3D space

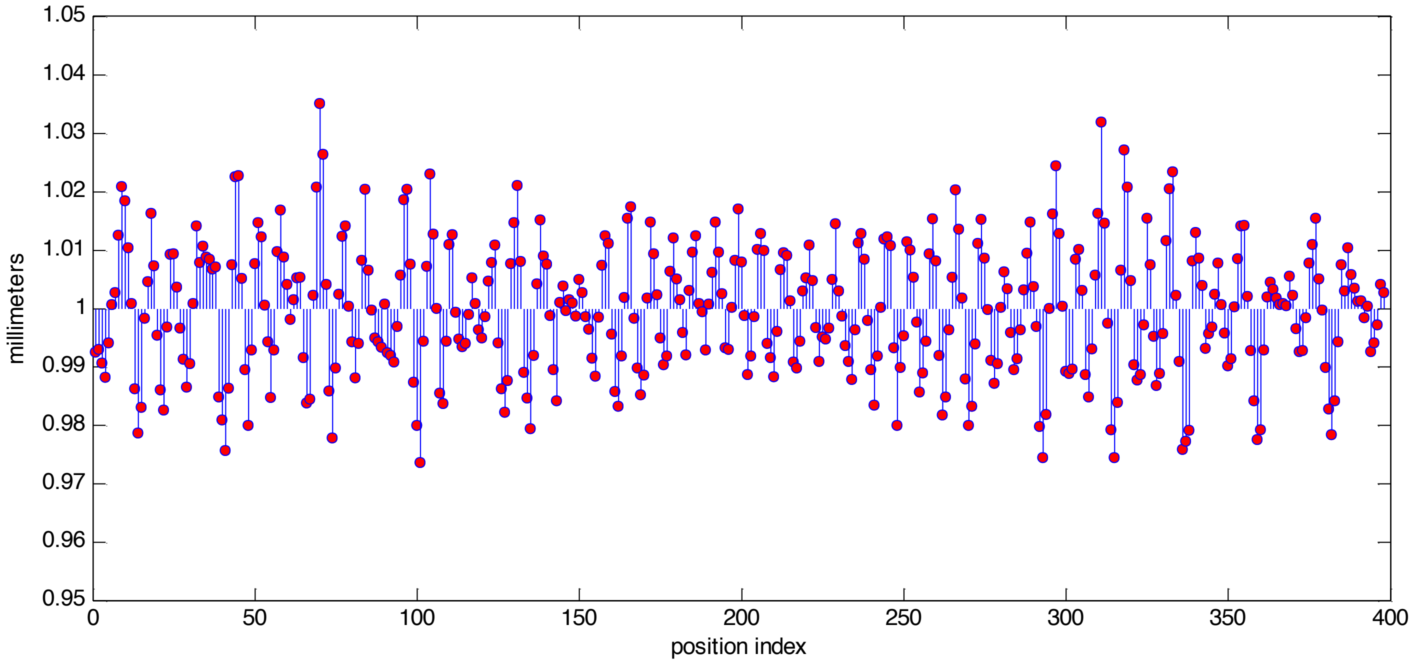
$$\underset{d_i}{\operatorname{argmin}} \sum_{k=1}^{N} \left\| F_{R,l_0+d_i l_n,I^*}(M_k) - m_{k,i} \right\|^2, i = 1, \dots, K$$

Independent estimation of the position of each camera over the line

Algorithm performance on synthetic dataset

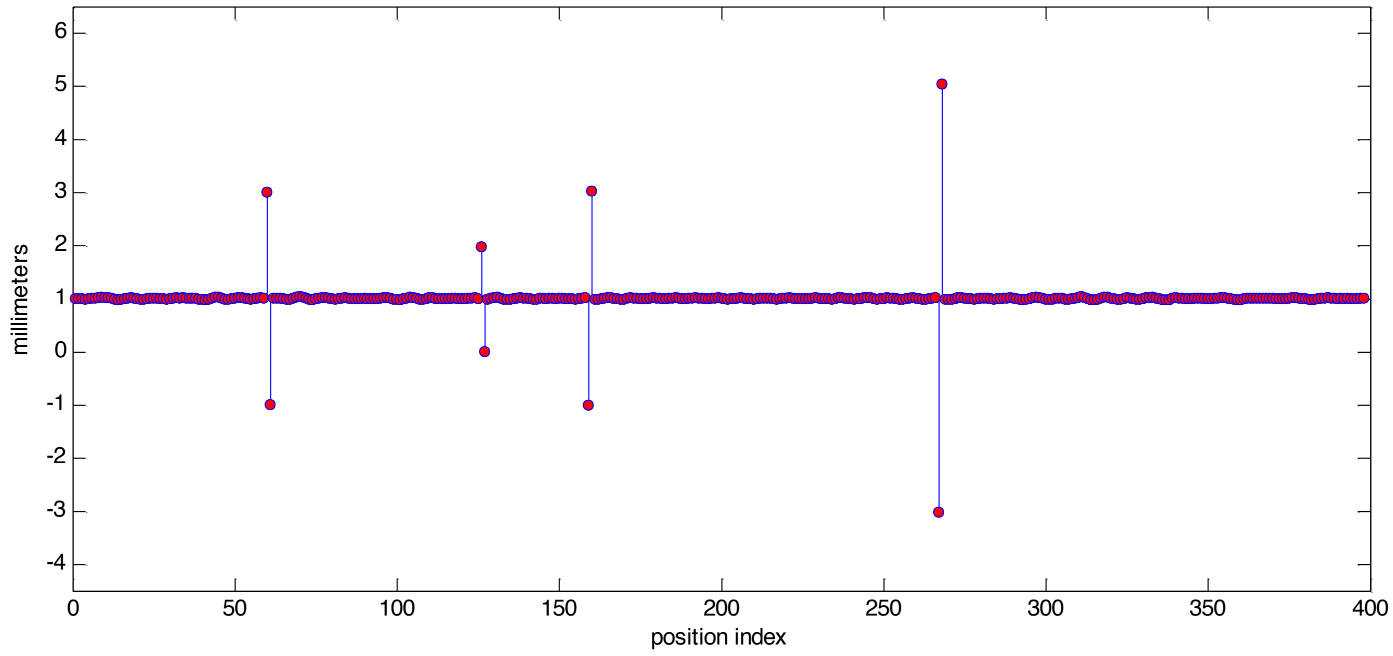


Algorithm performance on real dataset



Distances between estimated consecutive locations

Algorithm performance on real dataset with outliers

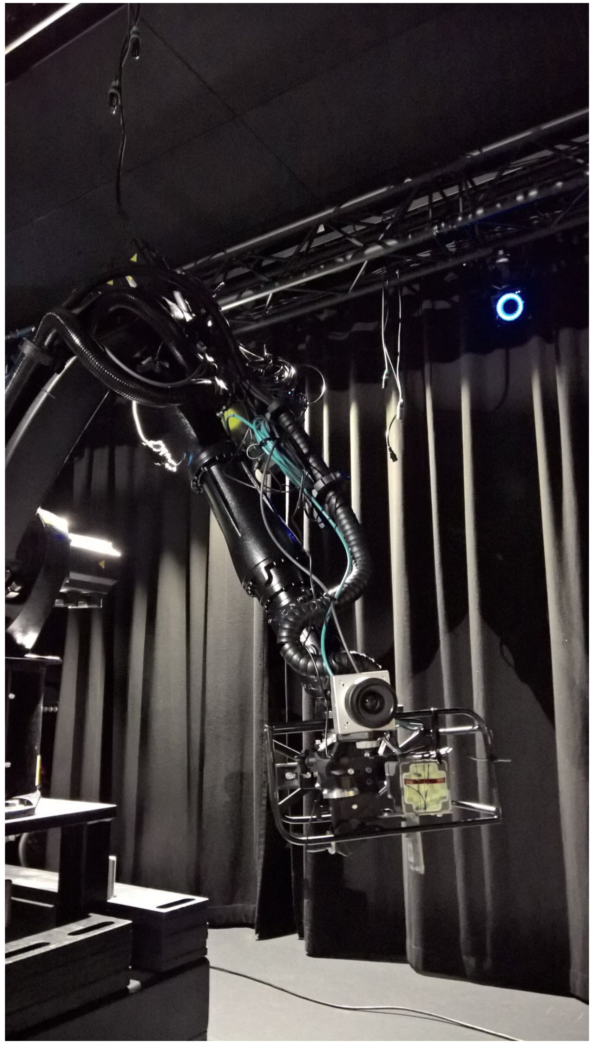


Distances between estimated consecutive locations

Conclusion

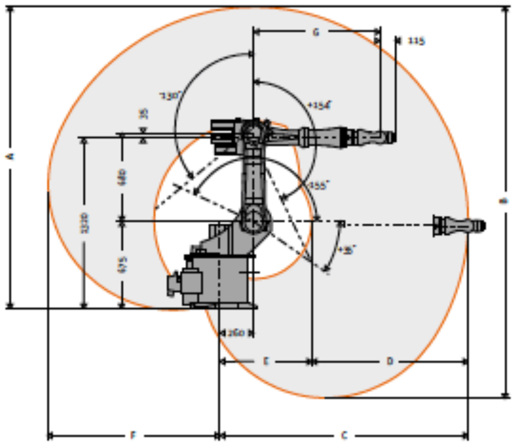
- A motorized linear positioning system allowing very fine light field sampling has been constructed
- Method for its precision verification has been developed
- Proposed calibration algorithm also provides estimates of the camera lens distortions and camera rotation during capture
- Having this data, one can model the light field sampling process with a higher accuracy

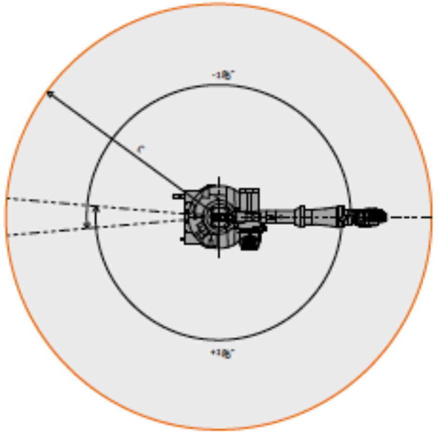
Robotic arm



KR 16 L6-2

Work envelope[1]	Dimensions A	Dimensions B	Dimensions C	Dimensions D	Dimensions E	Dimensions F	Dimensions G	Volume
KR 16 L6-2	2,326 mm	3,011 mm	1,911 mm	1,206 mm	705 mm	1,327 mm	970 mm	24 m³





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[1] Relative to intersection of axes 4/5.

Features and advantages

LONG REACH. Extension of the usable workspace, compared with that of the KR 16 L6-2, with a 300 mm arm extension.

FLEXIBLE. Variable installation variants offer high flexibility for different applications.

SPACE-OPTIMIZED. Low disruptive contours of the robot and streamlined design of the wrist ensure high accessibility, even in confined spaces.

SECURITY OF INVESTMENT. Model from the tried-and-tested, modular range of standard KR 16 L6-2 robots – ensuring planning security, high quality and availability.

	KR 16 L6-2
Max. reach	1,911 mm
Rated payload	6 kg
Rated suppl. load, arm/link arm/rot. column	10/–/20 kg
Maximum total load	36 kg
Pose repeatability	±0.05 mm
Number of axes	6
Mounting position	Floor, ceiling, wall
Variant	–
Robot footprint	500 mm x 500 mm
Weight (excluding controller), approx.	240 kg

Axis data/ Range of motion		Speed with rated payload 6 kg
Axis 1 (A1)	+/-185°	156°/s
Axis 2 (A2)	+35°/-155°	156°/s
Axis 3 (A3)	+154°/-130°	156°/s
Axis 4 (A4)	+/-350°	335°/s
Axis 5 (A5)	+/-130°	335°/s
Axis 6 (A6)	+/-350°	647°/s

Operating conditions

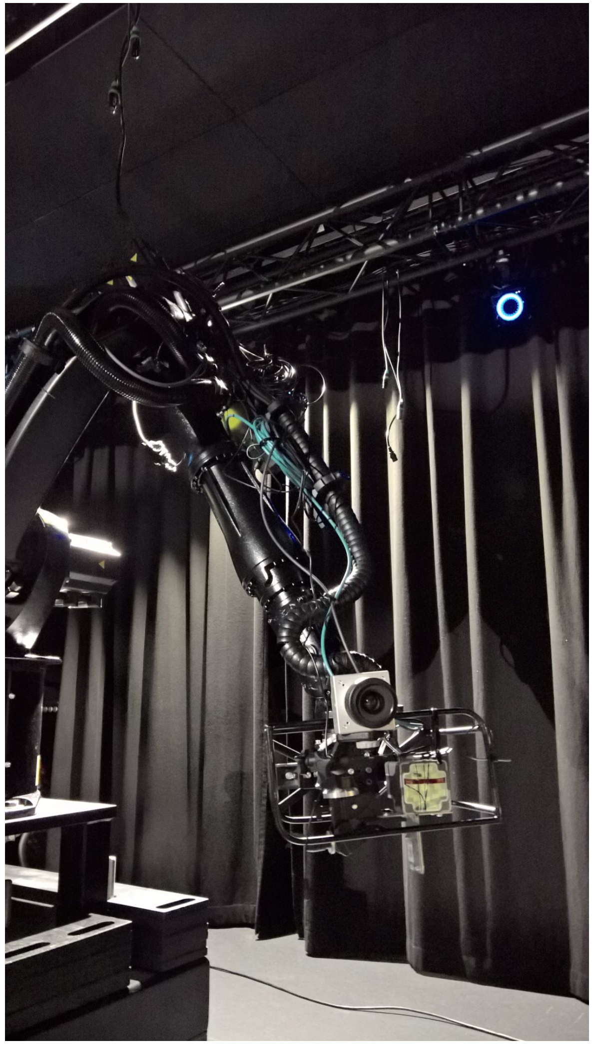
Ambient temperature	+5 °C to +55 °C

Protection rating

Protection rating, robot	IP 65
Protection rating, in-line wrist	IP 65

Controller	KR C4
Teach pendant	KUKA smartPAD

Camera: Optronis CP70-12-C-167

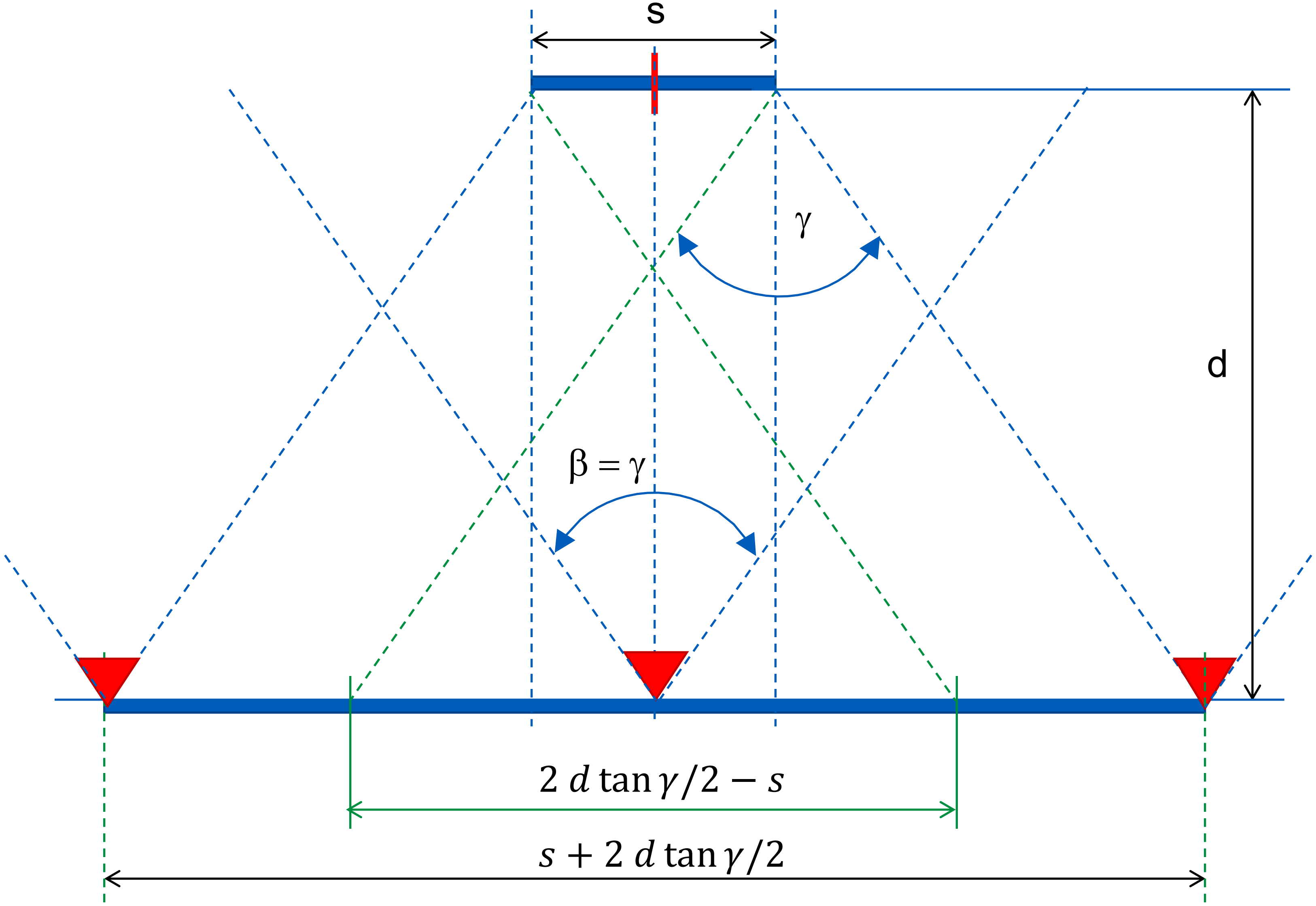


Resolution: 4080x3072 px

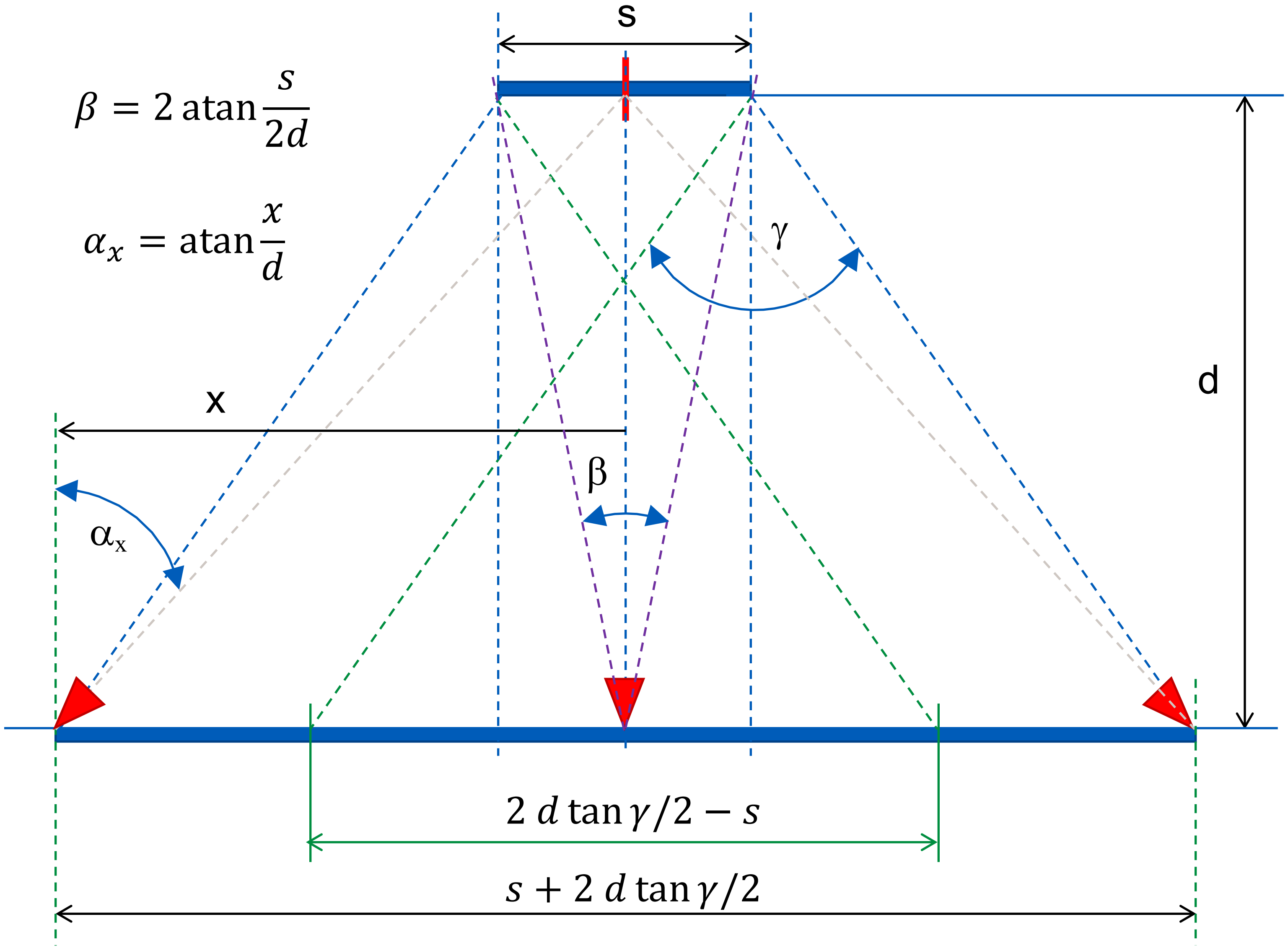
Frame rate: 166 (8 bit); 152 (10 bit)

Used lenses: Nikon FX or DX lenses with varying focal lengths

Content creation: linear cameras



Content creation: rotated cameras



Thank you for your attention