Minimal Solvers for Single-View Lens-Distorted Camera Auto-Calibration

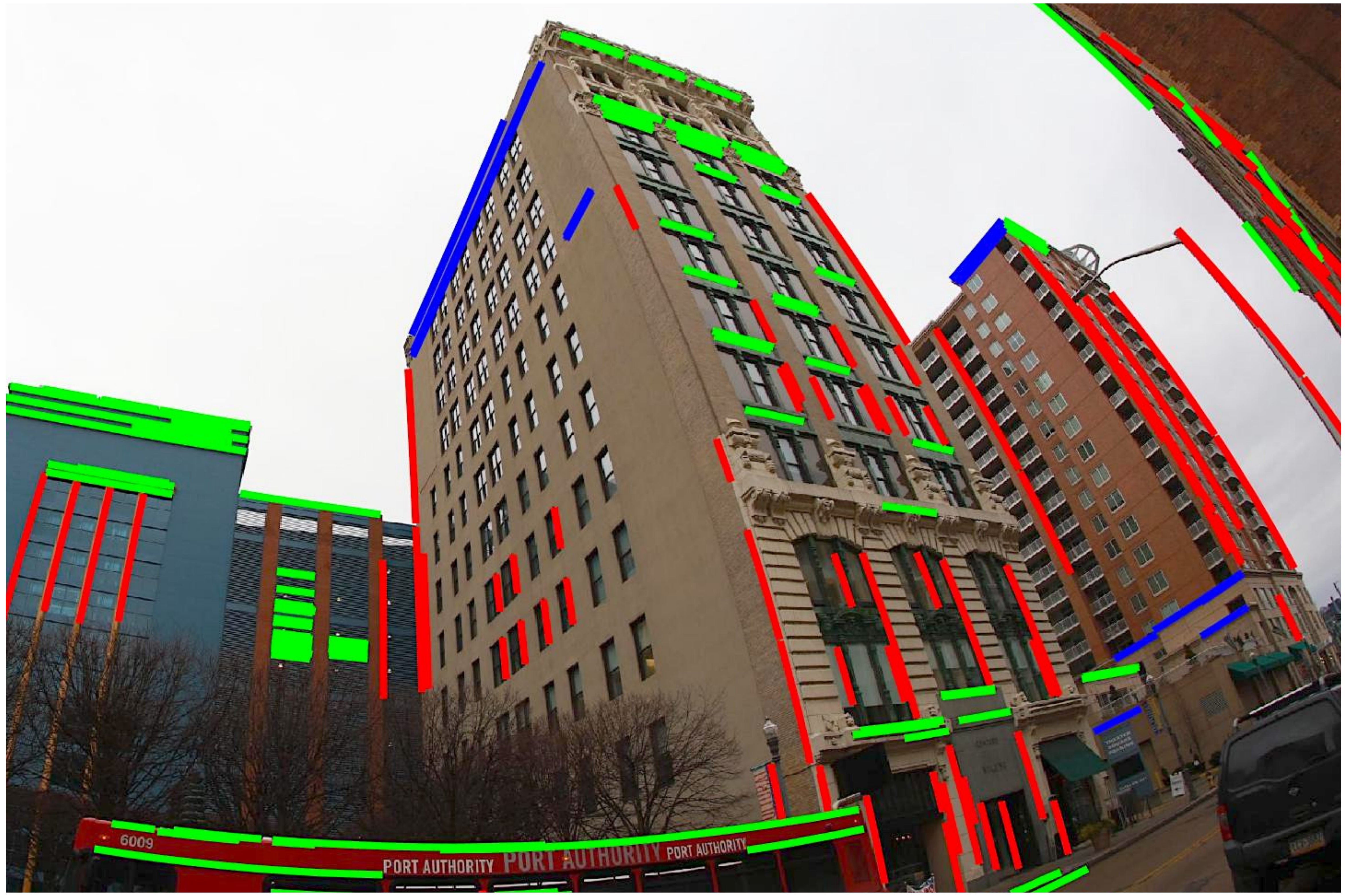
Yaroslava Lochman[1,2] Oles Dobosevych[1] Rostyslav Hryniv[1] James Pritts[2]

[1] Machine Learning Lab, Ukrainian Catholic University in Lviv
[2] Facebook Reality Labs Research in Pittsburgh

Single-View Auto-Calibration

Complementary Features

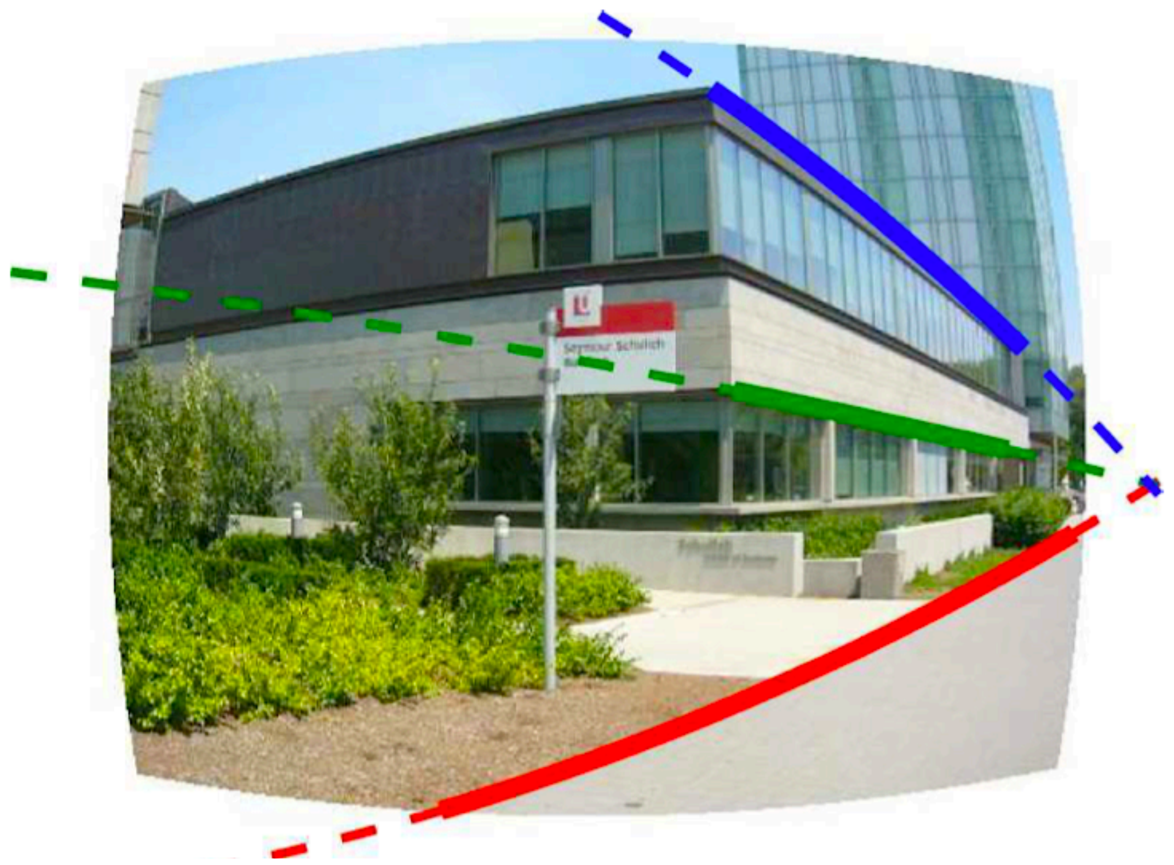
Parallel Scene Lines



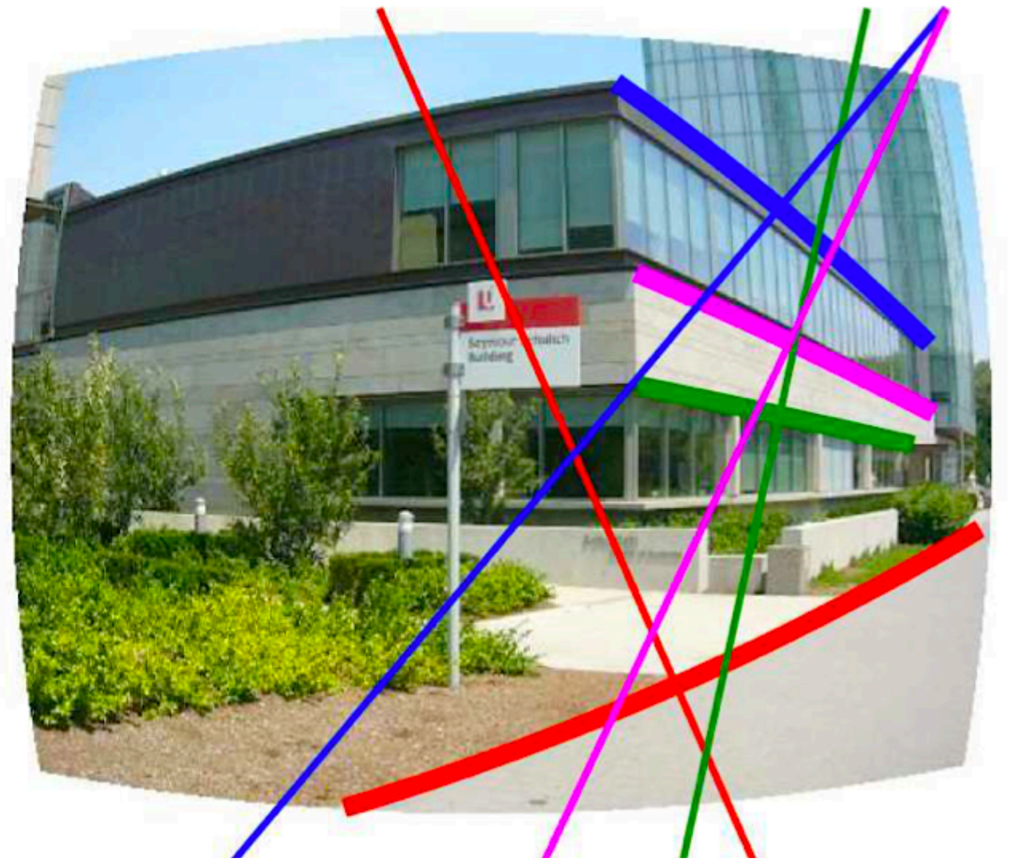
Translational Symmetries

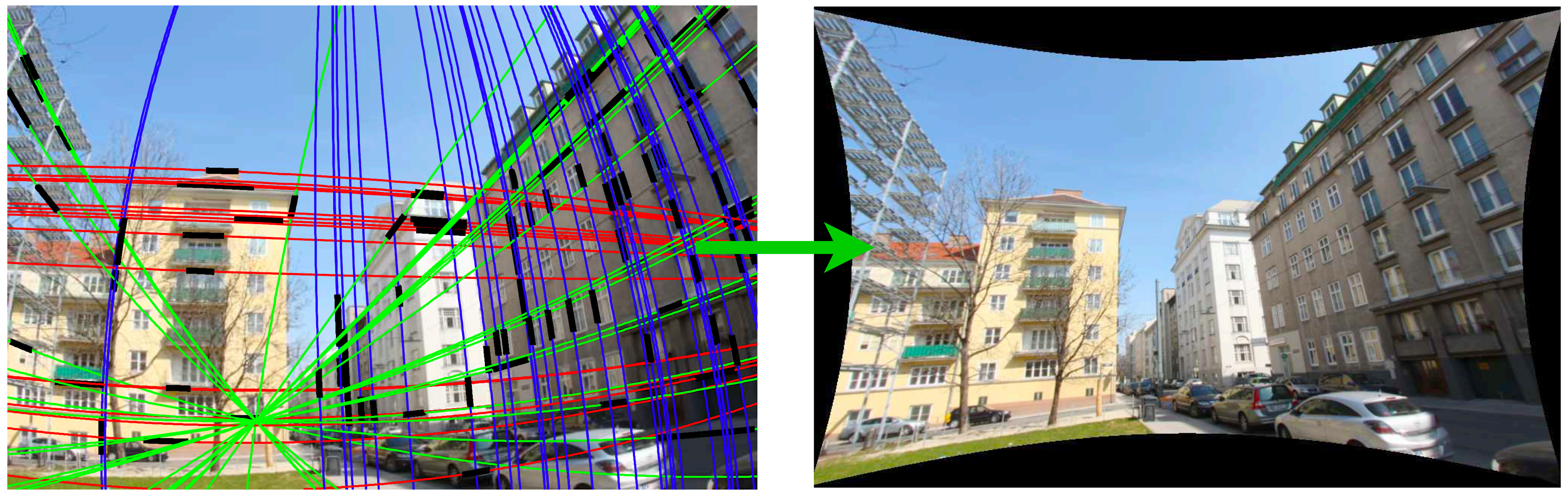
State of the Art

Wildenauer et al.:
5 circular arcs



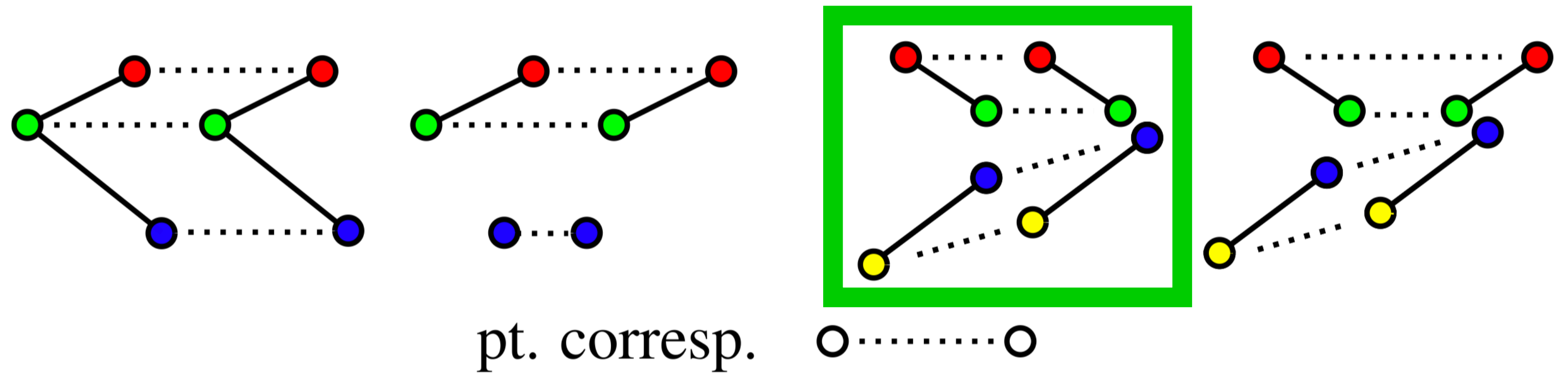
Antunes et al.:
7 circular arcs

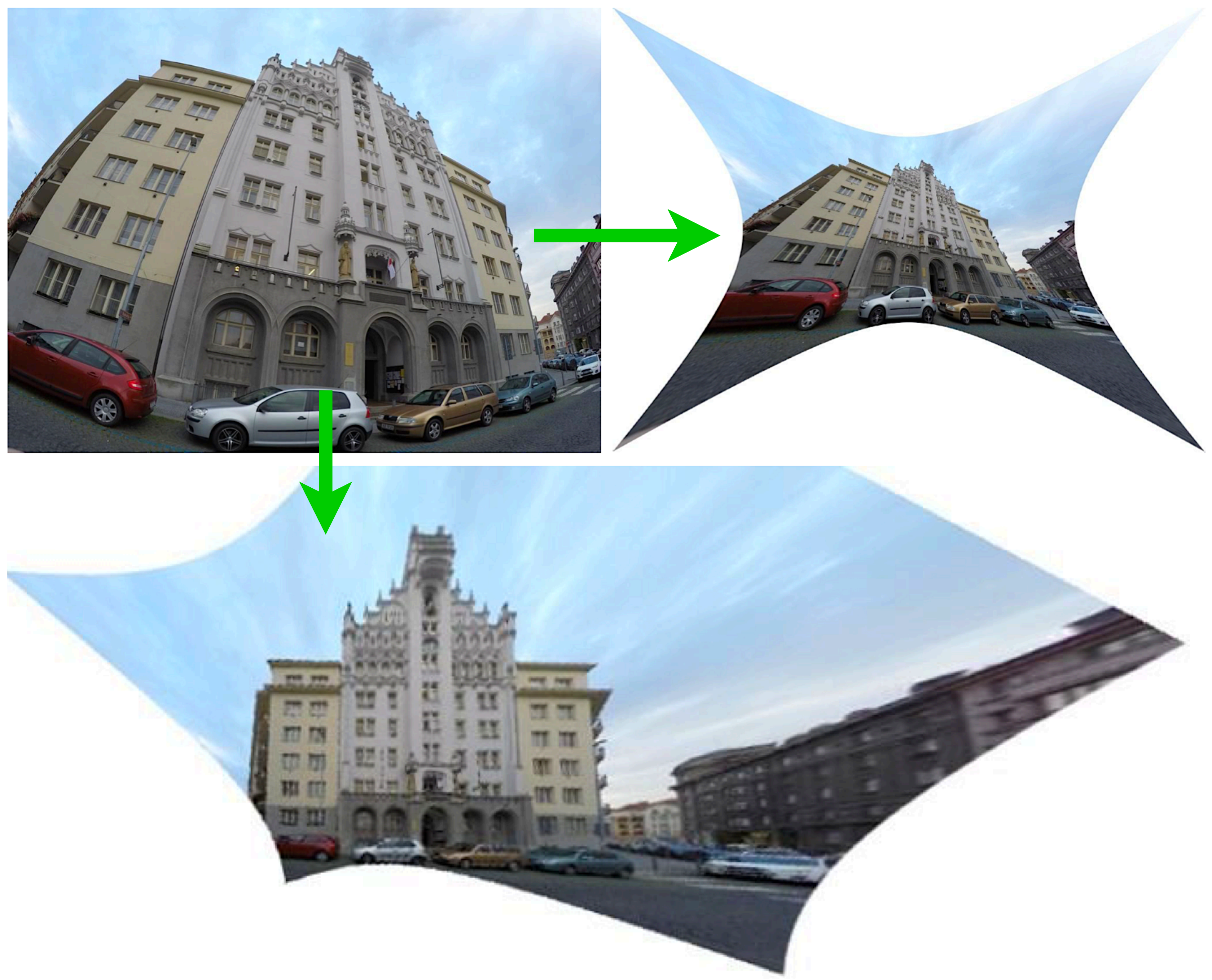




Circular arcs are ***hard to group*** *as imaged parallel scene lines*

Pritts et al.: 4 point correspondences

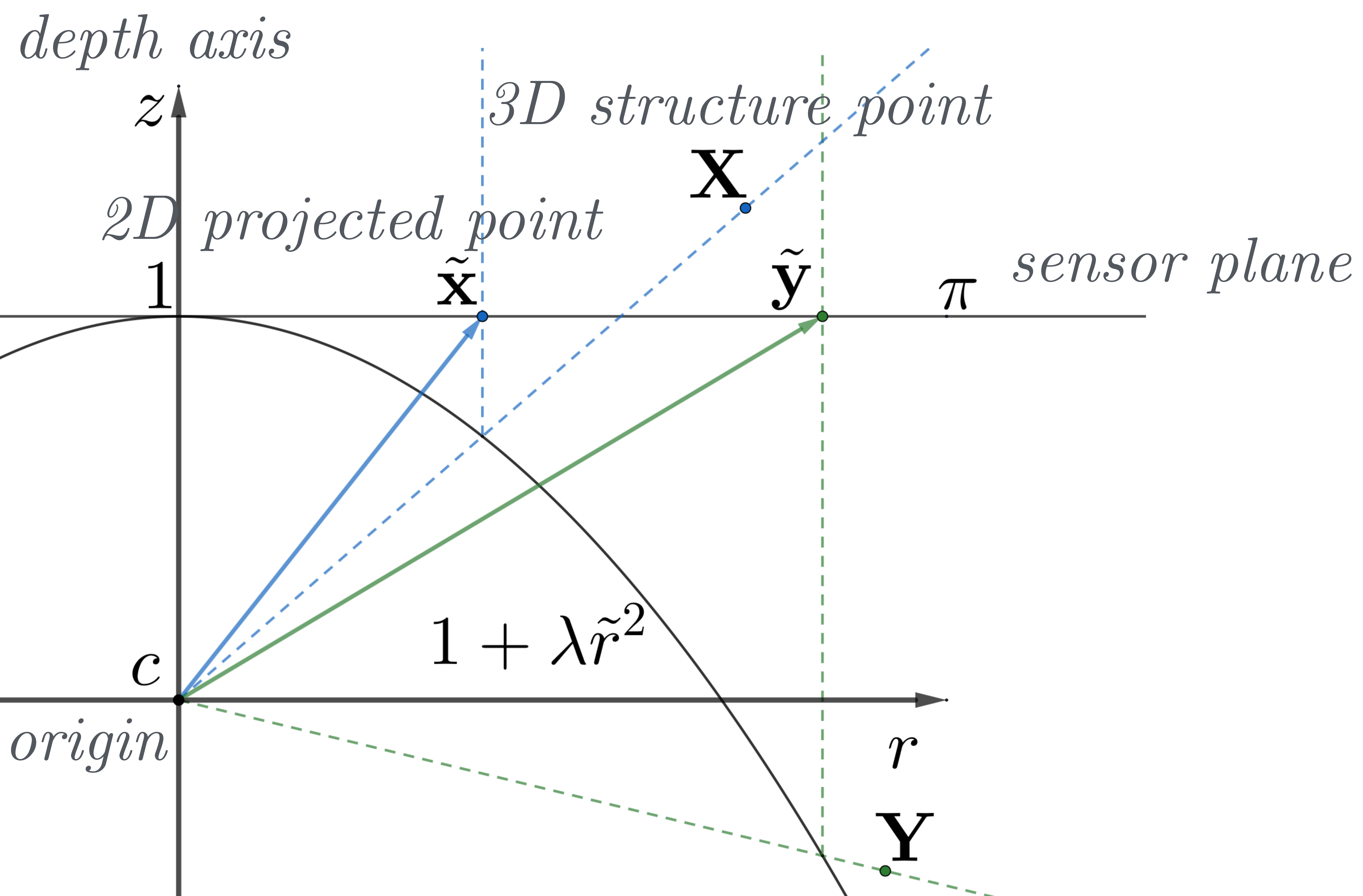




Covariant regions are ***noisy*** *thus provide less accuracy*

Camera Model

$$\gamma g(\tilde{\mathbf{x}}, \lambda) = \mathtt{K} \left[\mathtt{R} \mid \mathbf{t} \right] \mathbf{X}$$



$$g(\tilde{\mathbf{x}}, \lambda) = (\tilde{x}, \tilde{y}, 1 + \lambda \tilde{r}^2)^\top$$

division model parameter (λ)

$$\mathtt{K} = \mathrm{diag}(f, f, 1)$$

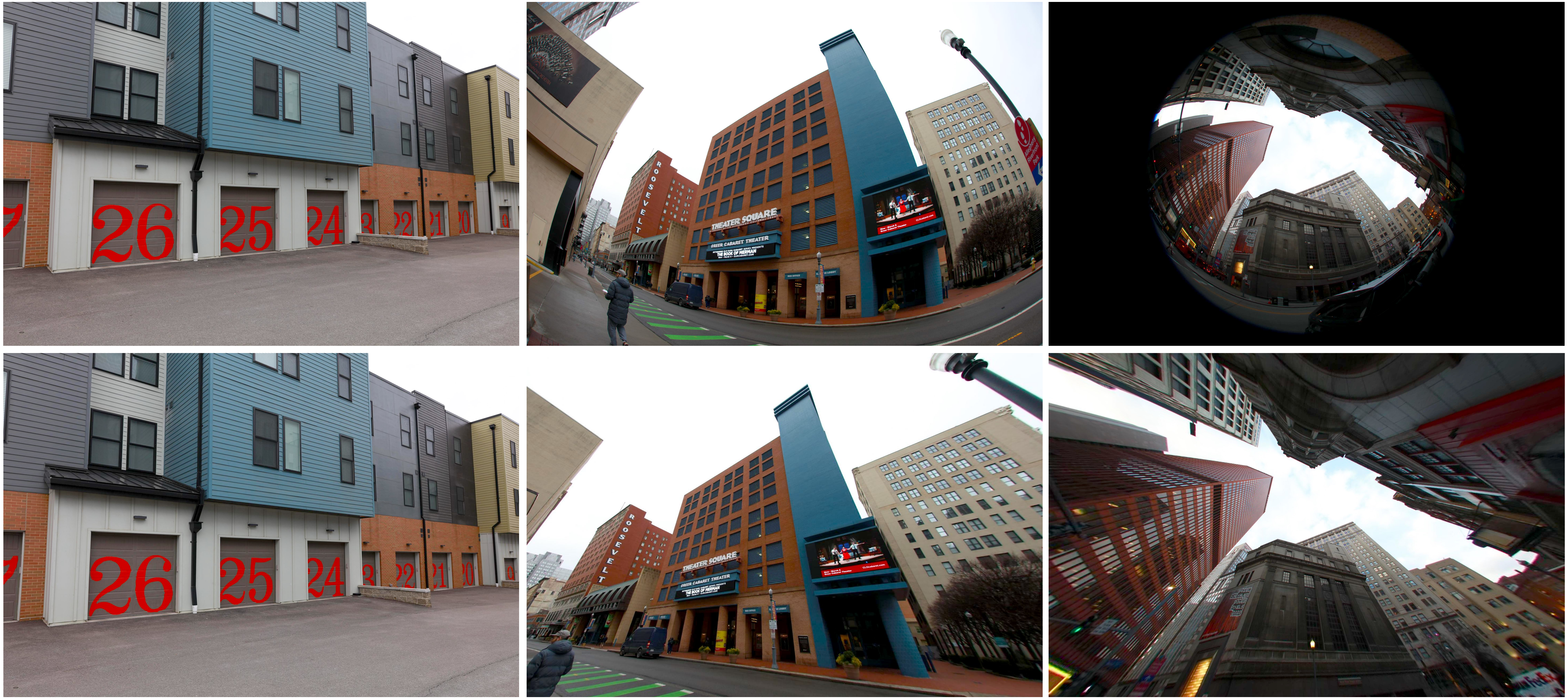
focal length (f)

Division Model of Undistortion

Sigma 24mm | Sigma 15mm | Sigma 8mm

Input

Undistorted



Vanishing Point as Meet of Lines

$$\mathbf{u}(\lambda) = \mathbf{m}(\lambda) \times \mathbf{m}'(\lambda)$$

vanishing point

undistorted images of parallel lines

Vanishing Point as Meet of Lines

$$\mathbf{u}(\lambda) = \mathbf{m}(\lambda) \times \mathbf{m}'(\lambda)$$

vanishing point — **u**(λ)

undistorted images of parallel lines — **m**(λ), **m**′(λ)

constructed from

point correspondences extracted from imaged translational symmetries

or

circular arcs as imaged scene lines

Coplanar Vanishing Points

Constraints

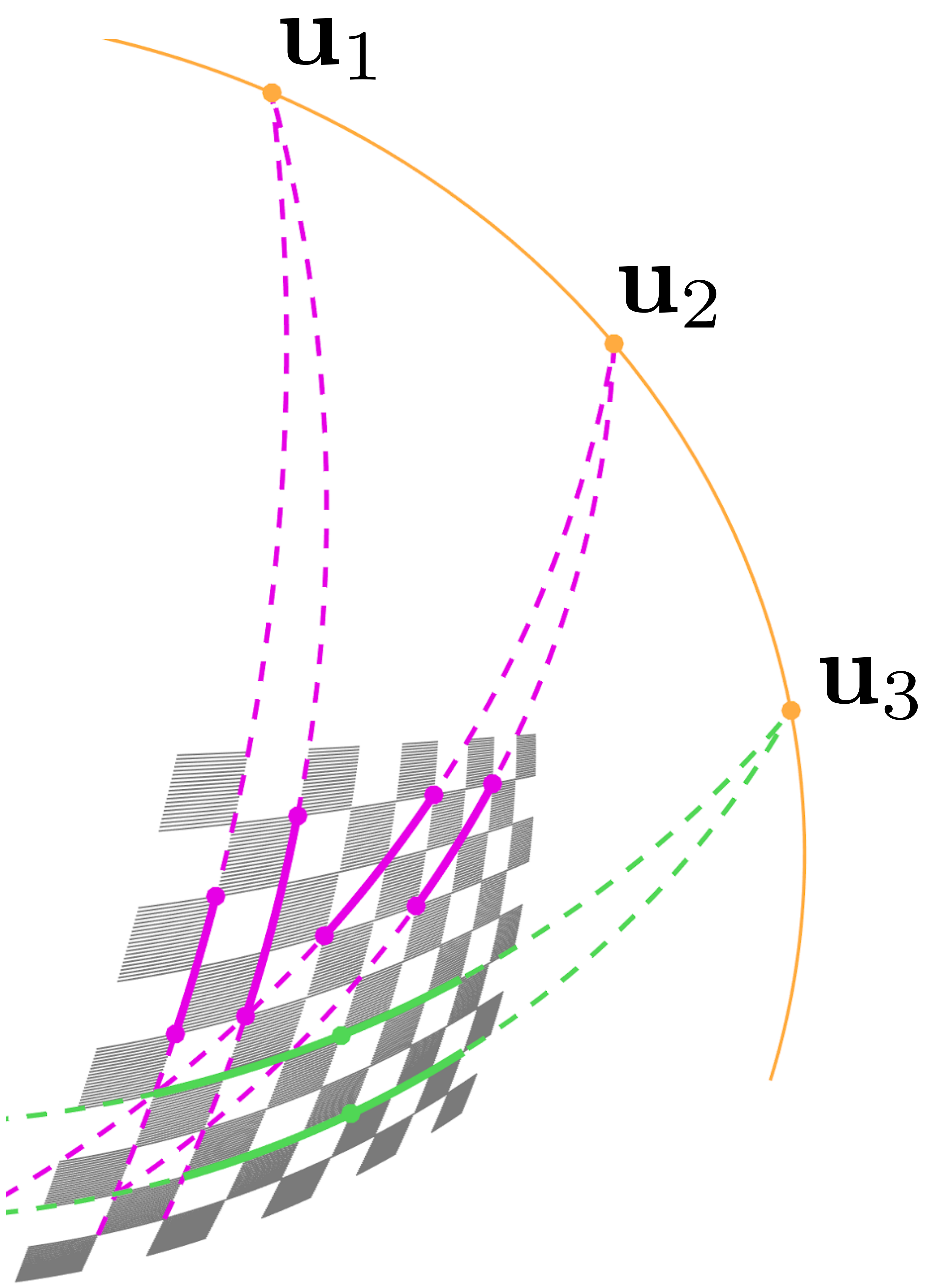
$$\mathbf{u}_1(\lambda)^\top \mathbf{l} = 0$$
$$\mathbf{u}_2(\lambda)^\top \mathbf{l} = 0$$

$$\mathbf{u}_3(\lambda)^\top \mathbf{l} = 0$$

Solvers	*# Sol of λ*
4PC+2CA	4
2PC+4CA	4
6CA	4
5CA*	8

C++ runtime $\sim$ 1μs

PC — point correspondences
CA — circular arcs



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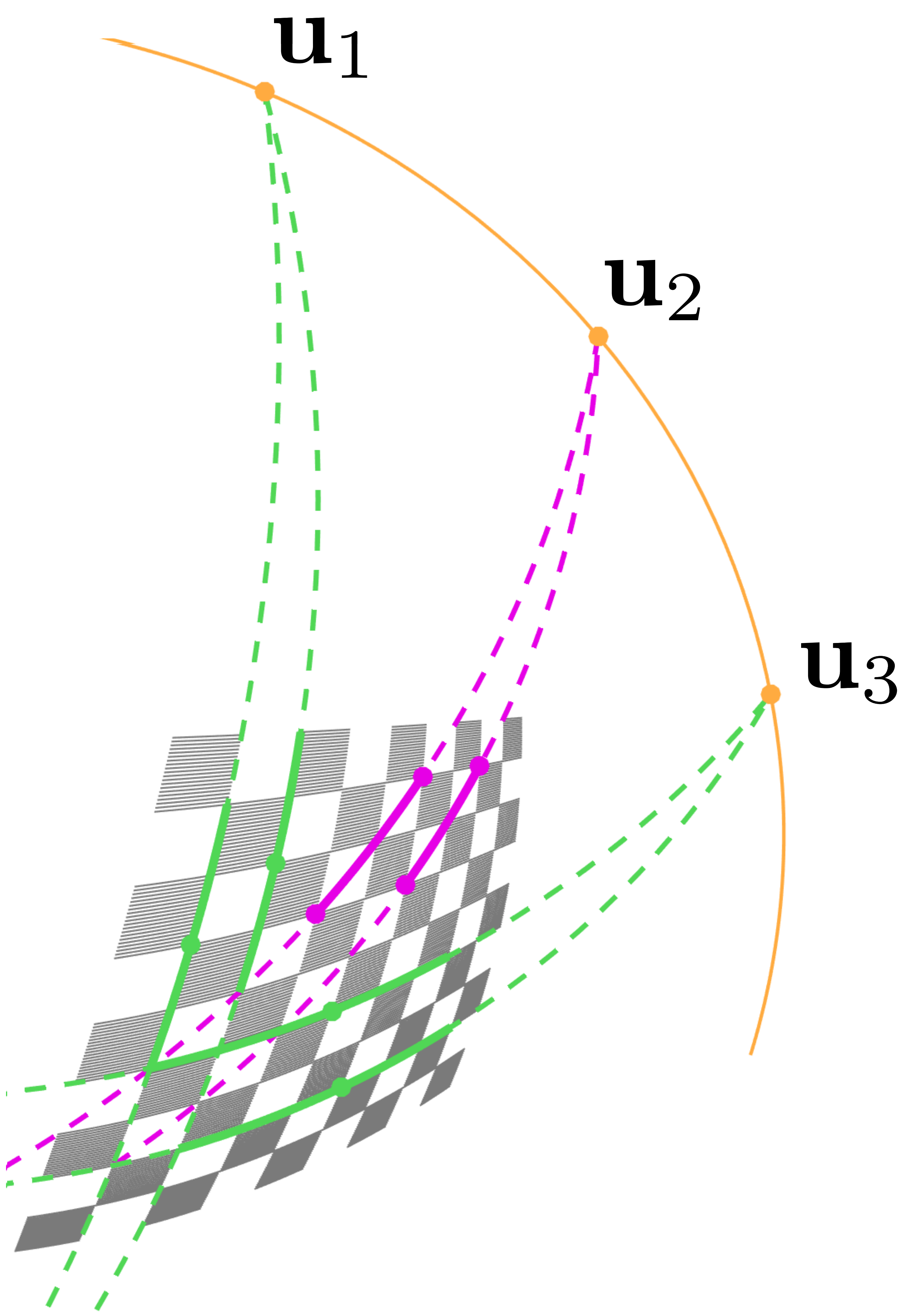

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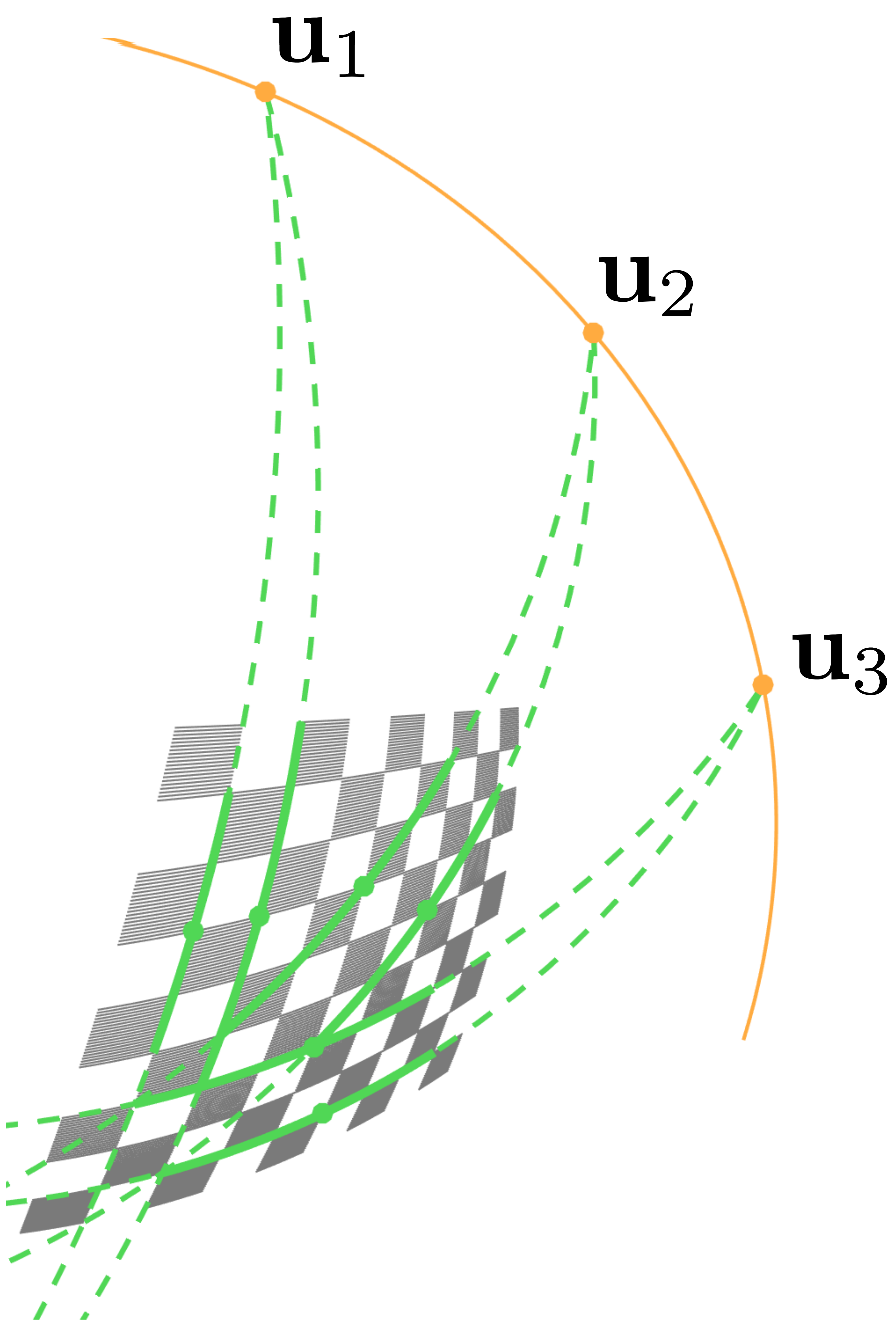

Coplanar Vanishing Points

Constraints

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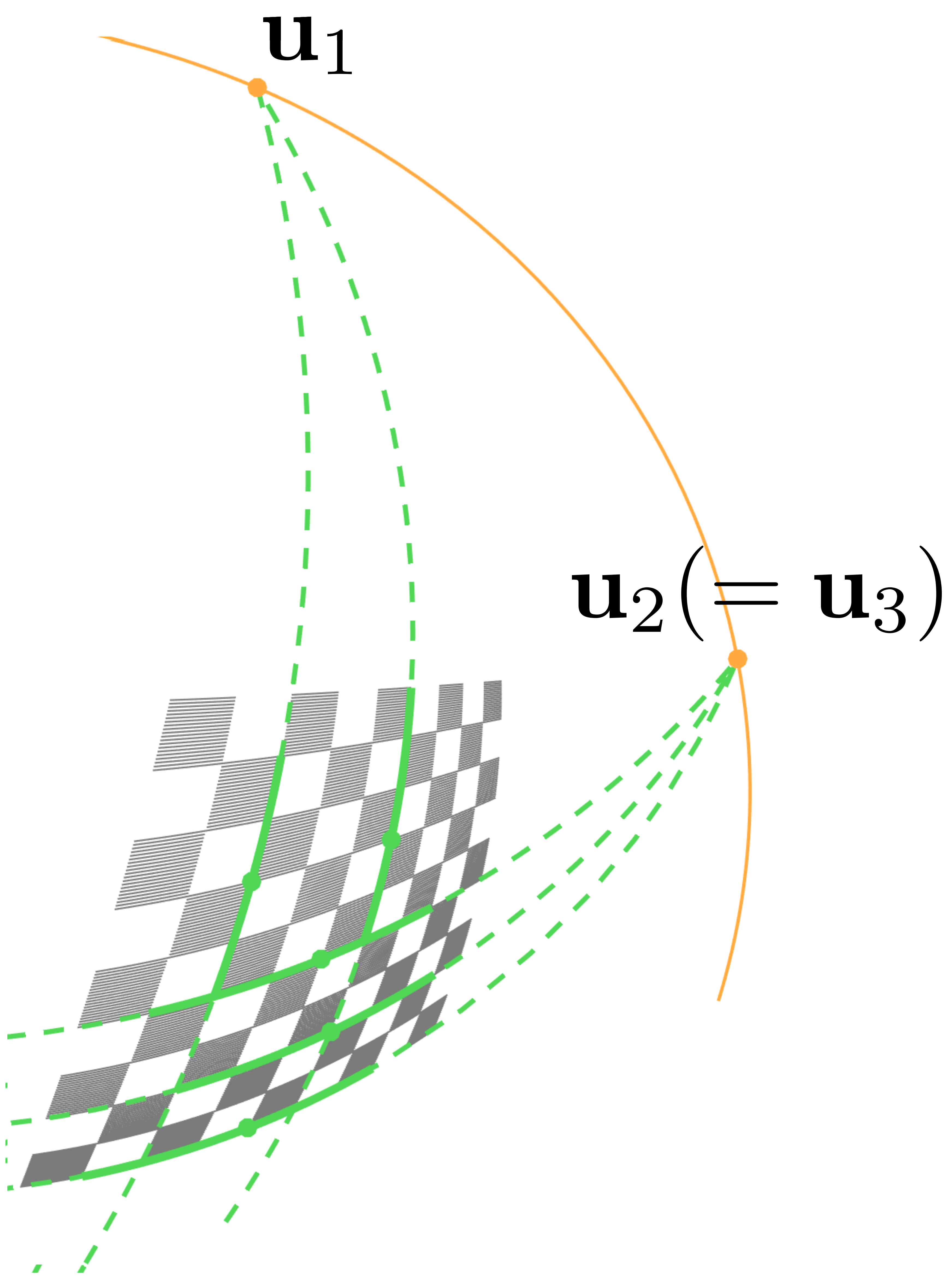
$$\mathbf{u}_2(\lambda)^\top \mathbf{l} = 0$$
$$\mathbf{u}_3(\lambda)^\top \mathbf{l} = 0$$
$$\mathbf{u}_2(\lambda) \times \mathbf{u}_3(\lambda) = \mathbf{0}$$

Solvers	*# Sol of λ*
4PC+2CA	4
2PC+4CA	4
6CA	4
5CA*	8

C++ runtime $\sim 1\mu s$

PC — point correspondences
CA — circular arcs



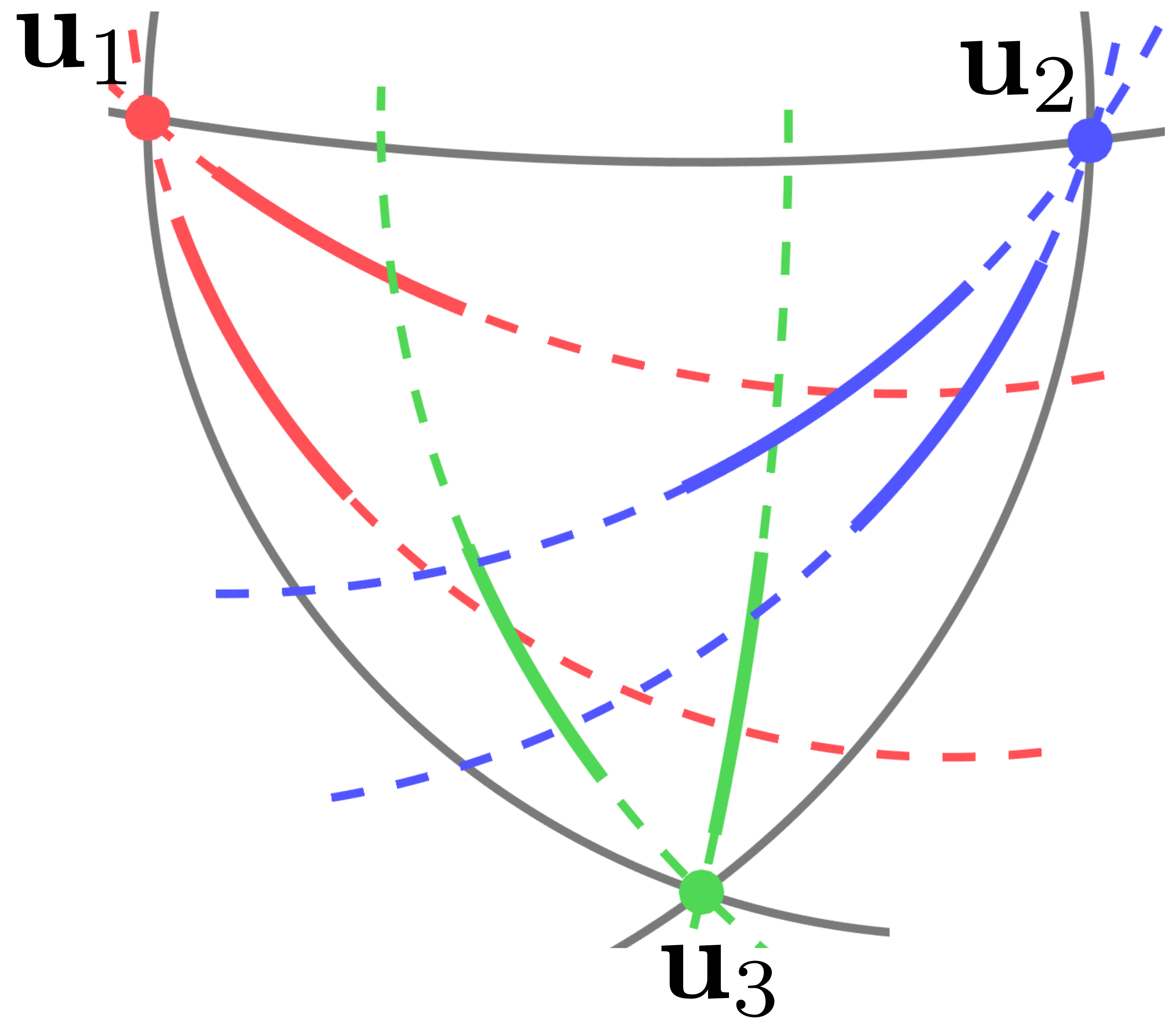
Orthogonal Vanishing Points

Constraints

$$\mathbf{u}_1(\lambda)^\top \omega(f)\mathbf{u}_2(\lambda) = 0$$
$$\mathbf{u}_1(\lambda)^\top \omega(f)\mathbf{u}_3(\lambda) = 0$$
$$\mathbf{u}_2(\lambda)^\top \omega(f)\mathbf{u}_3(\lambda) = 0$$

Solvers	*# Sol of* λ
4PC+2CA	12
2PC+4CA	12
6CA	12
5CA*	8

C++ runtime $\sim$ *1*μ*s*



Orthogonal Vanishing Points

Constraints

$$\mathbf{u}_1(\lambda)^\top \omega(f)\mathbf{u}_2(\lambda) = 0$$
$$\mathbf{u}_1(\lambda)^\top \omega(f)\mathbf{u}_3(\lambda) = 0$$
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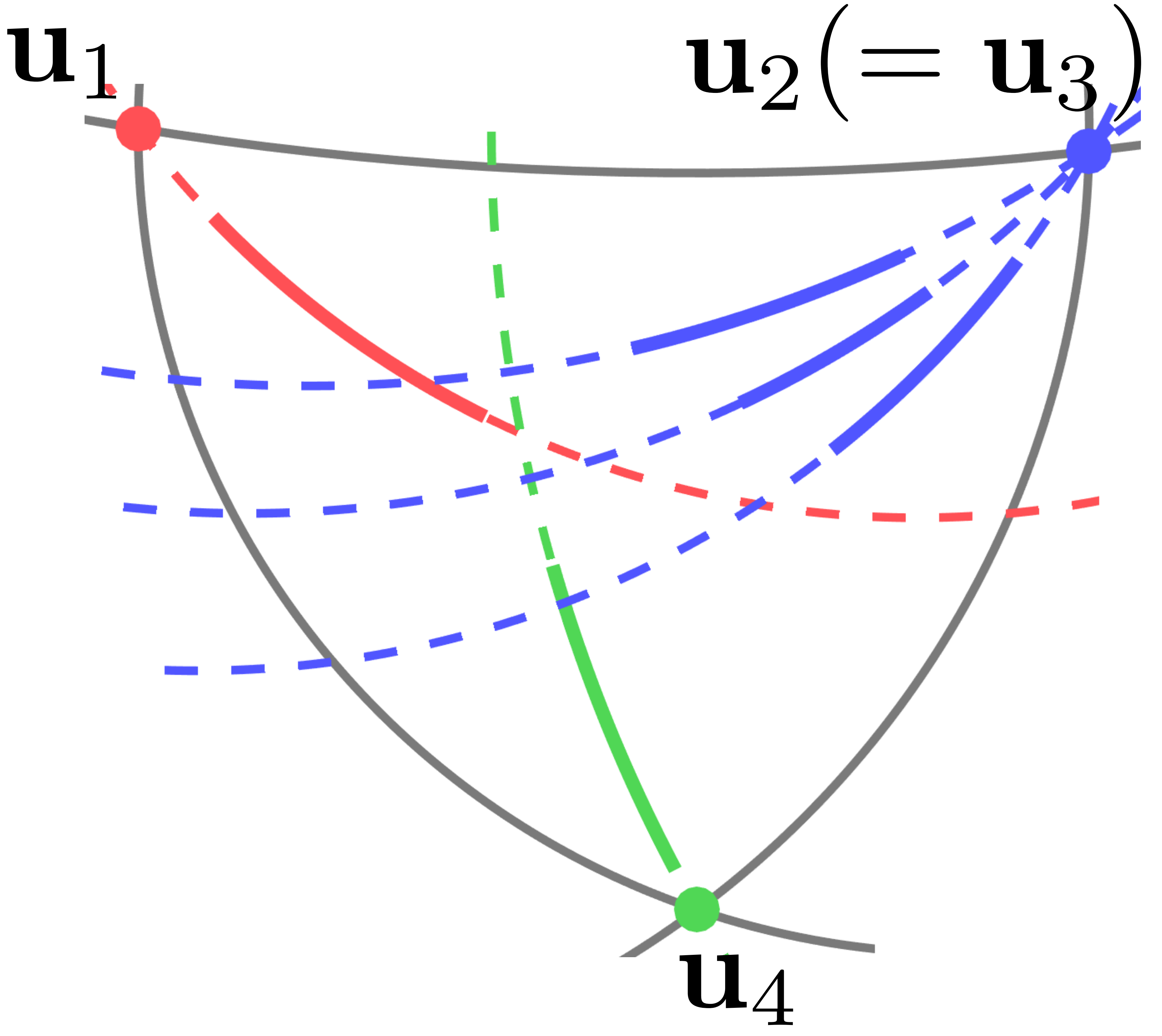
$$\mathbf{u}_2(\lambda) \times \mathbf{u}_3(\lambda) = \mathbf{0}$$

Solvers	*# Sol of λ*
4PC+2CA	12
2PC+4CA	12
6CA	12
5CA*	8

C++ runtime $\sim$ *1μs*



Method

Input

→

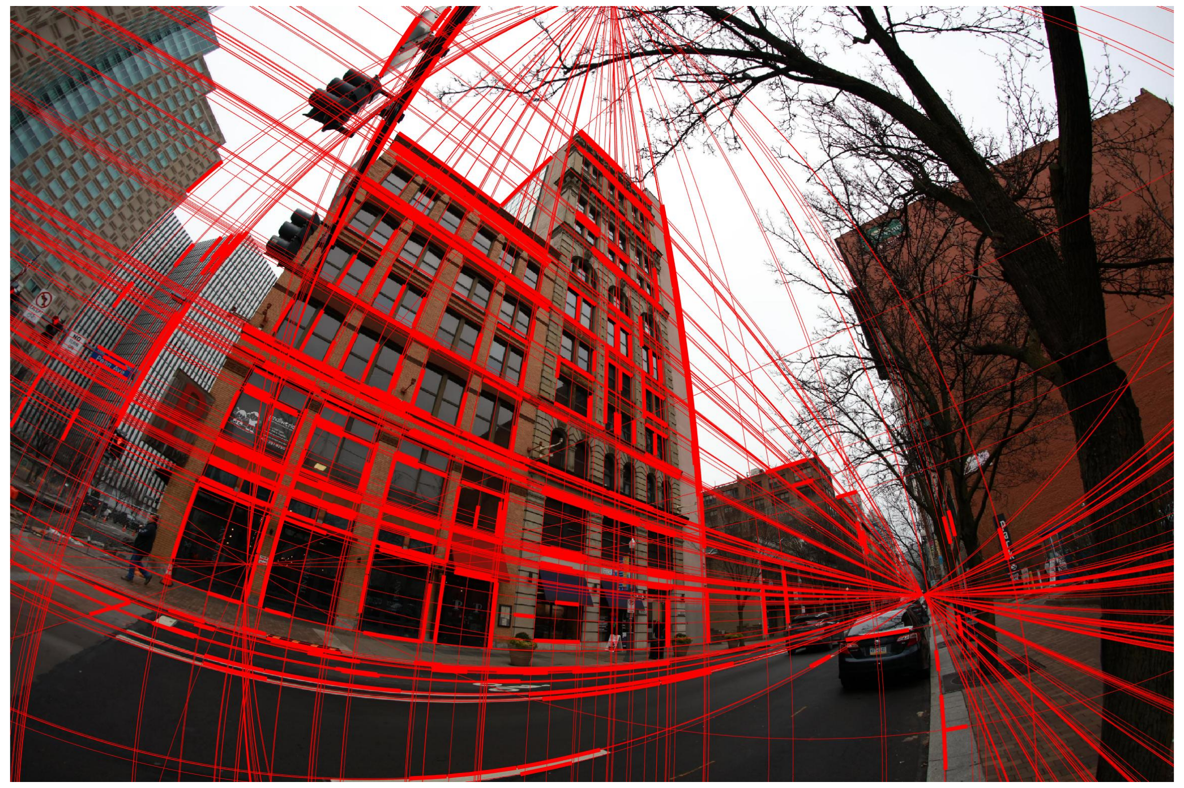
Feature Extraction

Arcs: Canny +
Ramer–Douglas–Peucker +
NLS Circle Fit

Regions: MSER + LAF +
RootSIFT +
Agglomerative Clustering

→

Measurements



Method

Measurements

List of Solvers + Priors

$[\mathbf{2PC{+}4CA}, \mathbf{6CA}]$

$[0.4, 0.6]$

Hybrid LO-RANSAC

Local Optimization

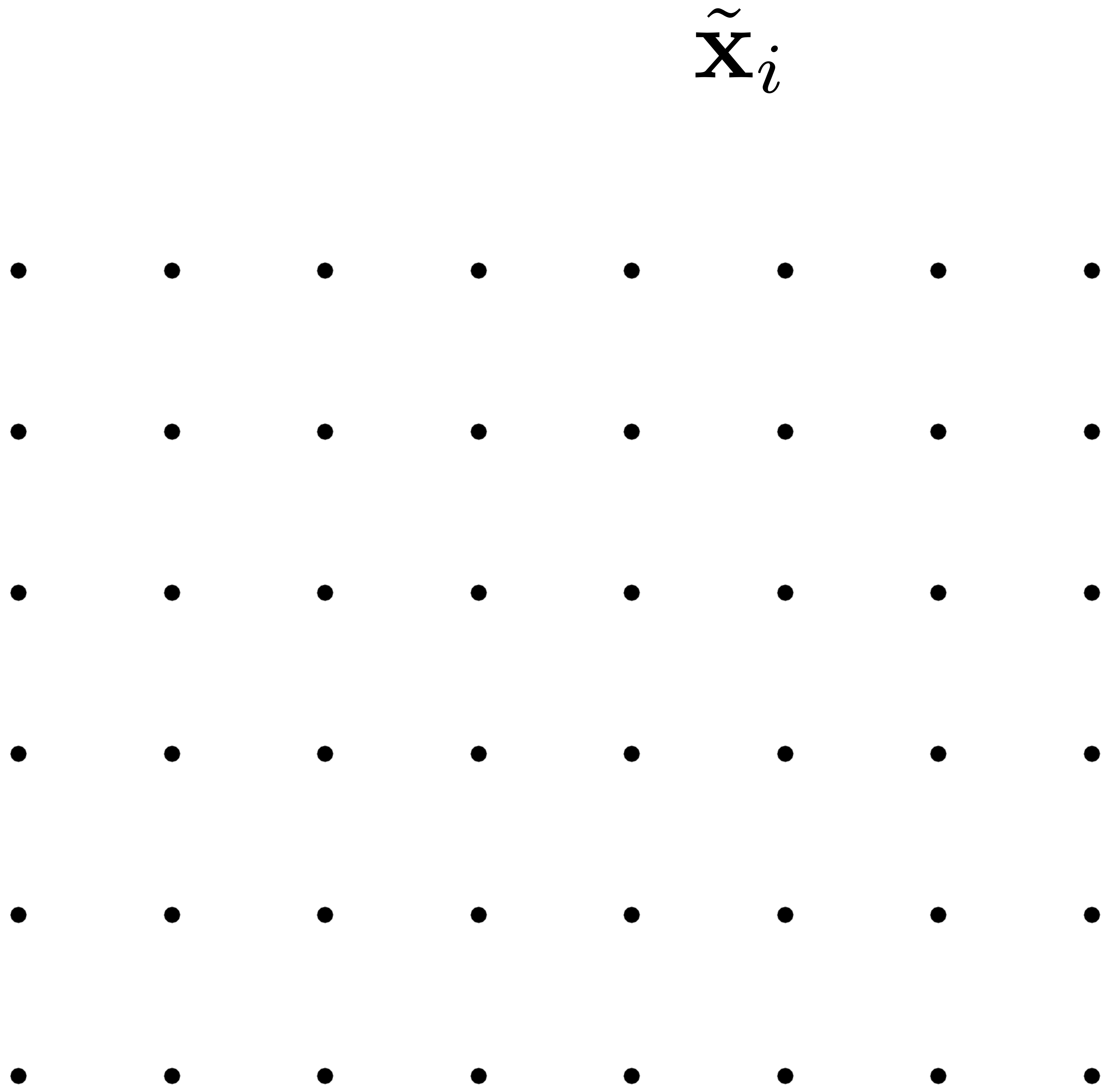
Refine camera geometry with circles fitted to arcs

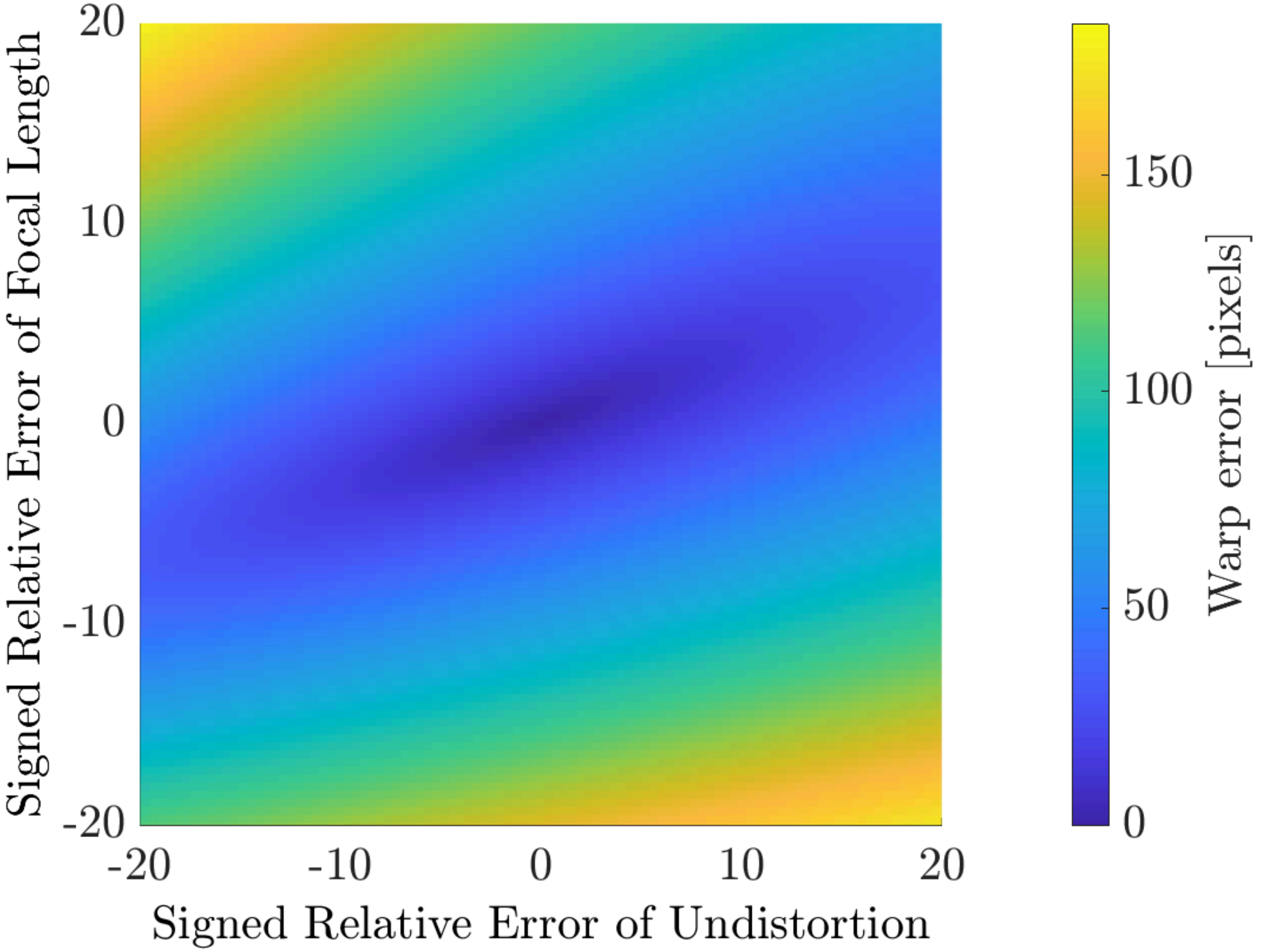
Auto-calibration

$\lambda, f, \mathtt{R}$

Warp Error

Geometric measure of calibration accuracy

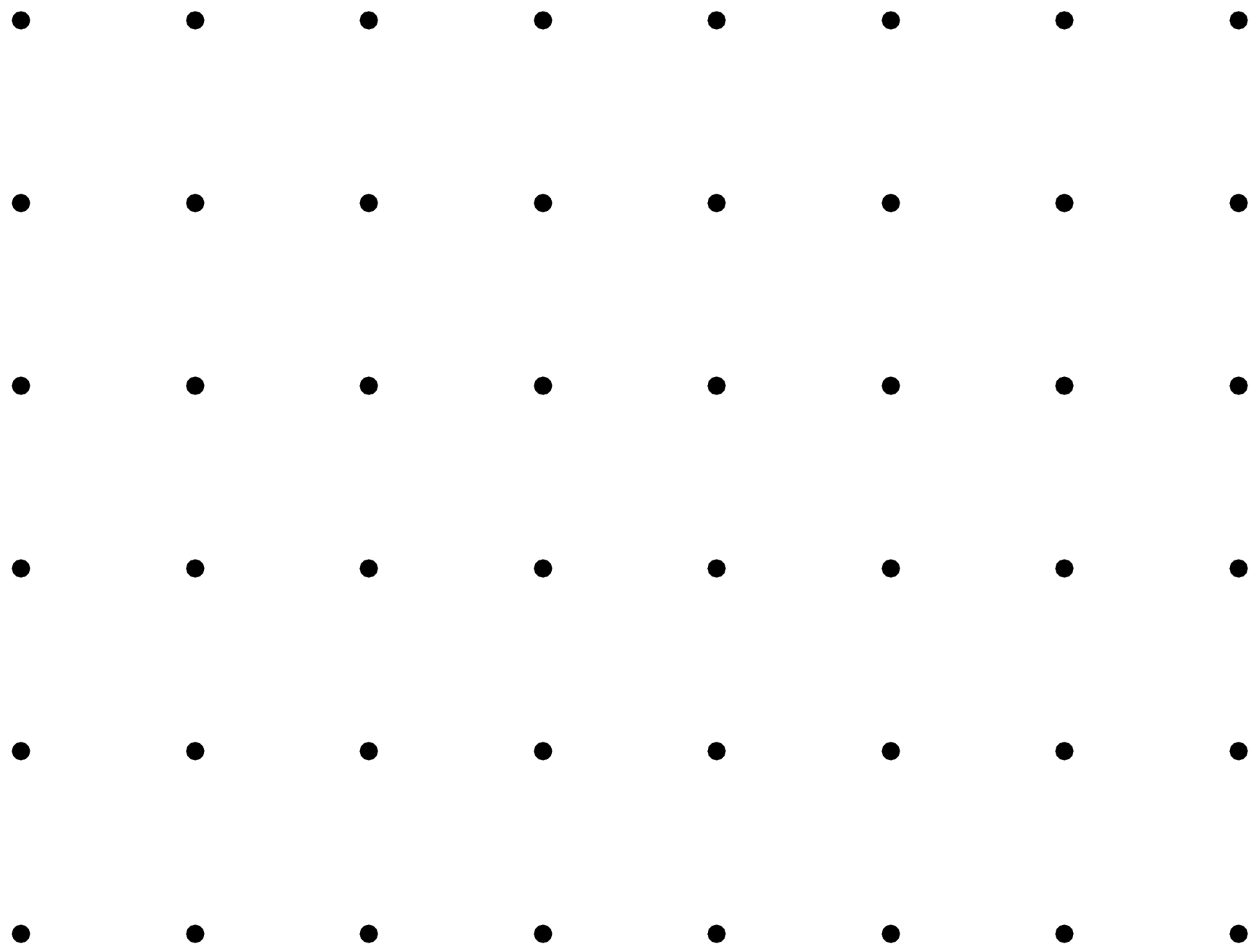


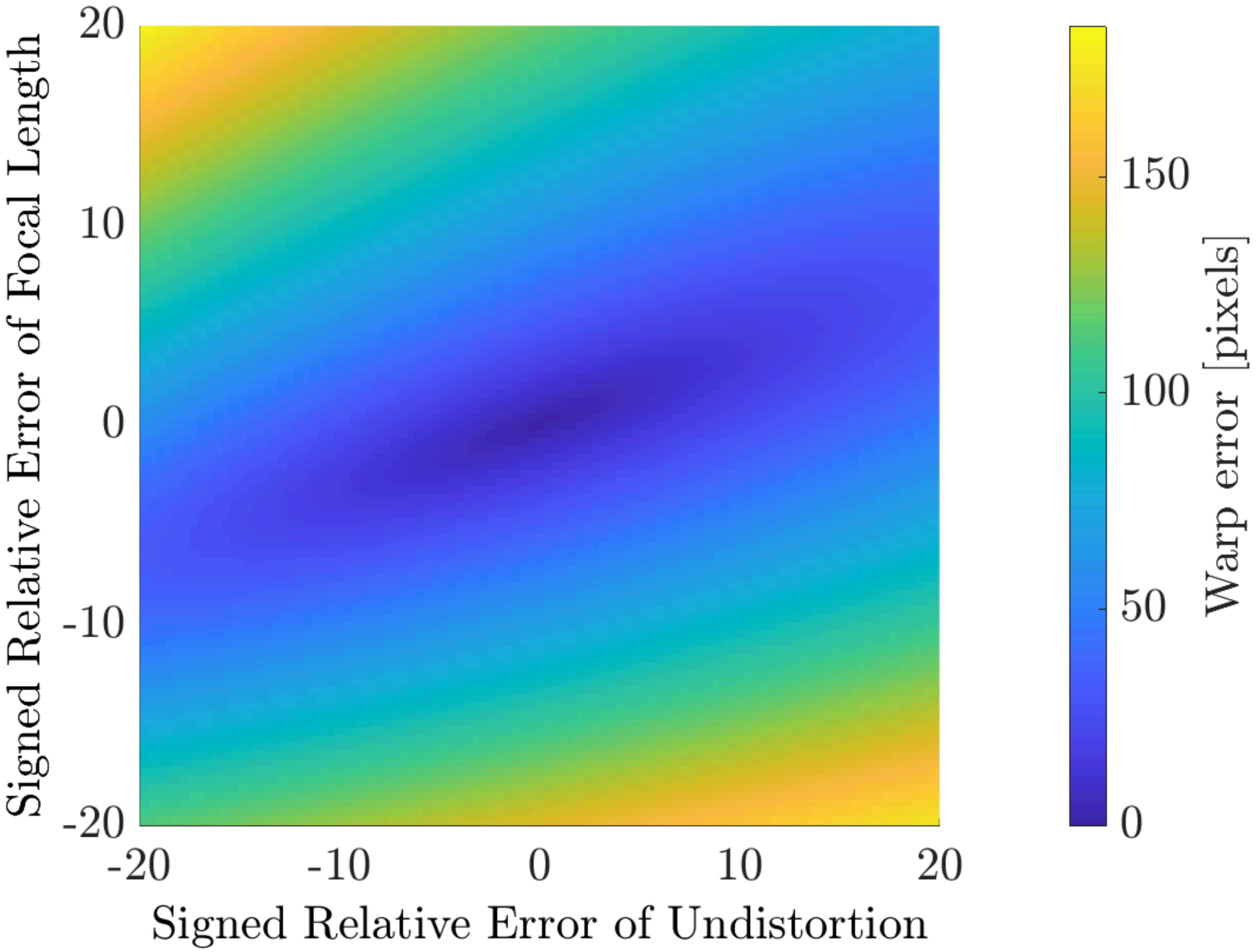


Warp Error

Geometric measure of calibration accuracy

$$\mathtt{K}^{-1} g(\tilde{\mathbf{x}}_i, \lambda)$$

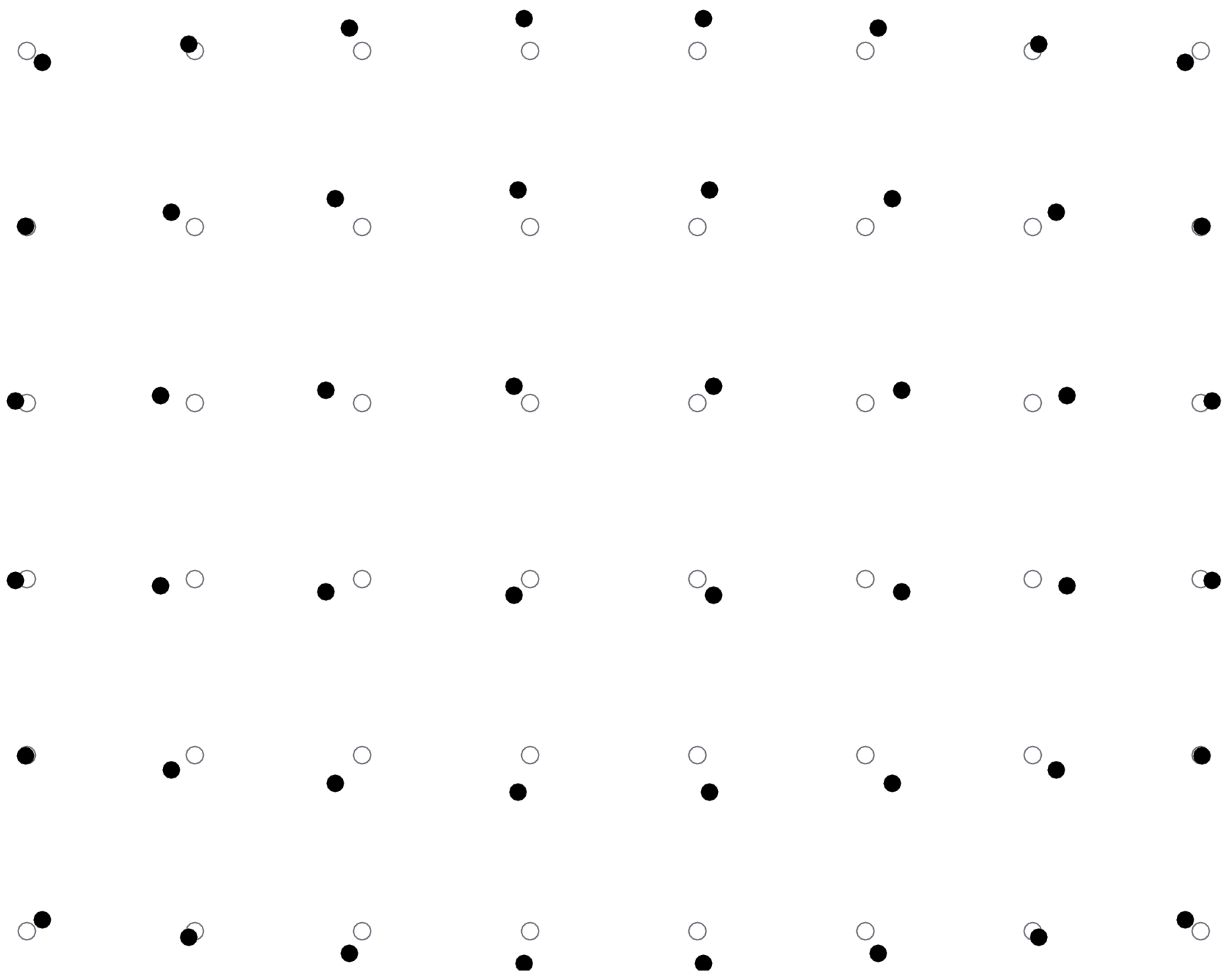


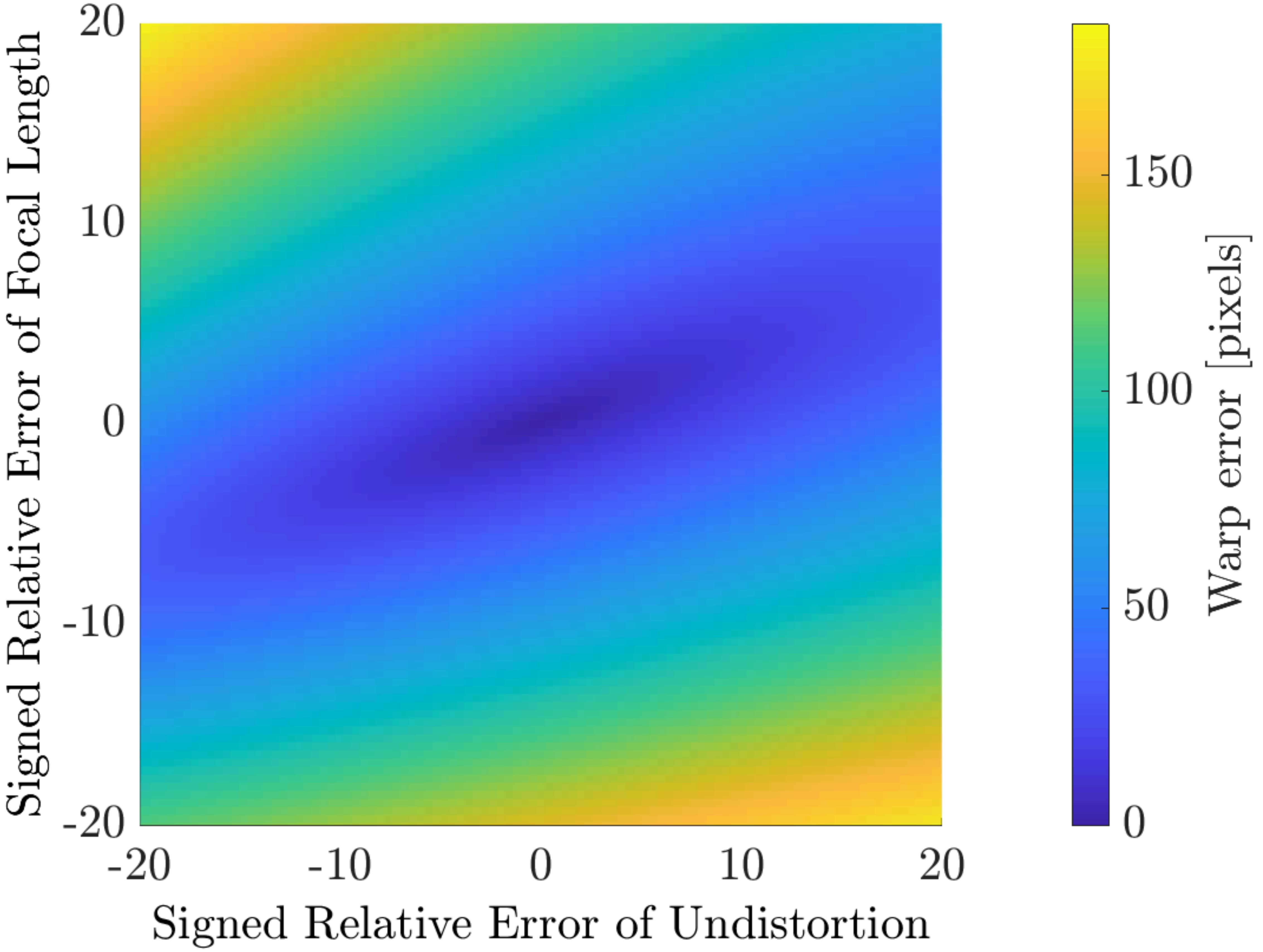


Warp Error

Geometric measure of calibration accuracy

$$g^d(\hat{\mathtt{K}}\mathtt{K}^{-1}g(\tilde{\mathbf{x}}_i, \lambda), \hat{\lambda})$$

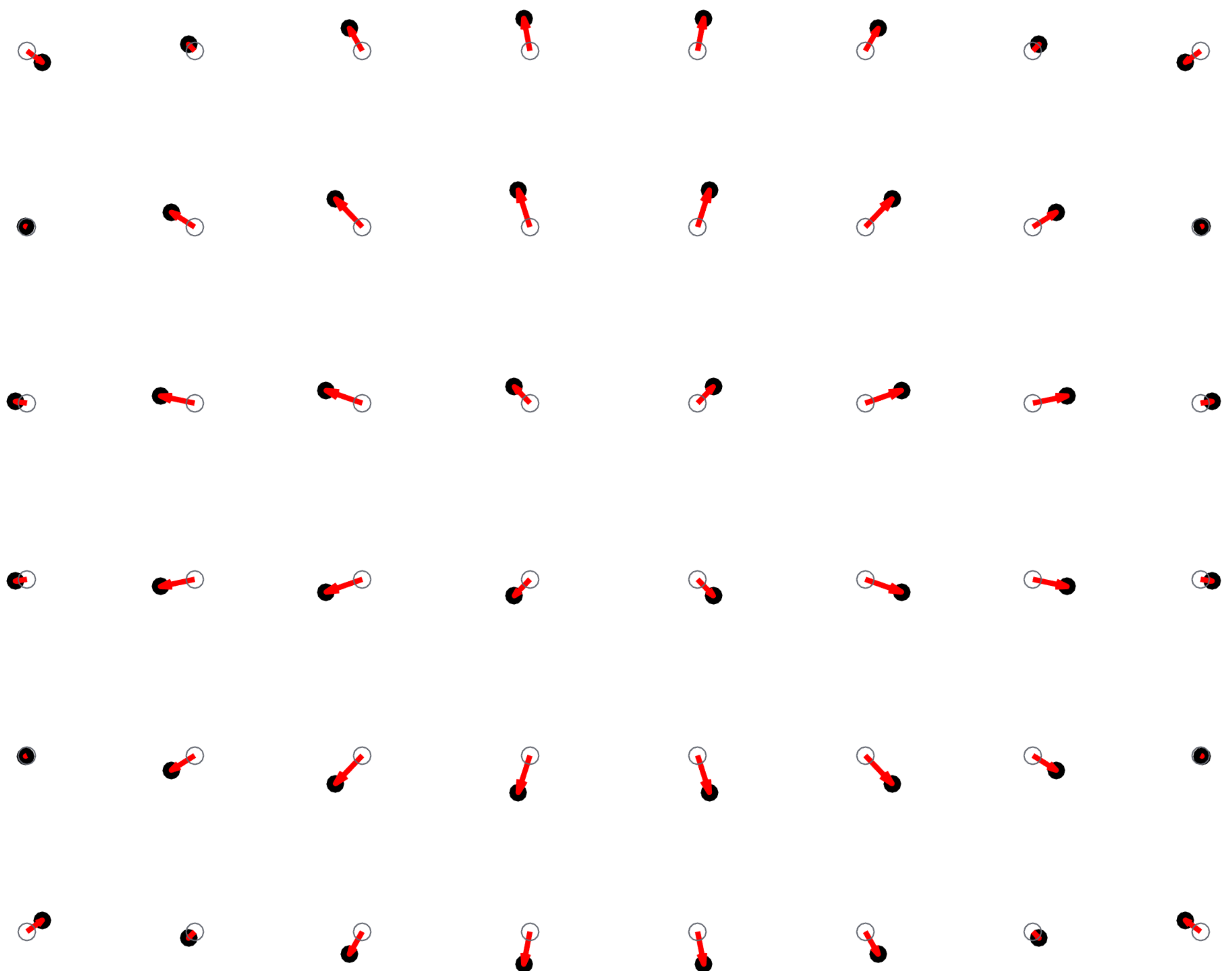


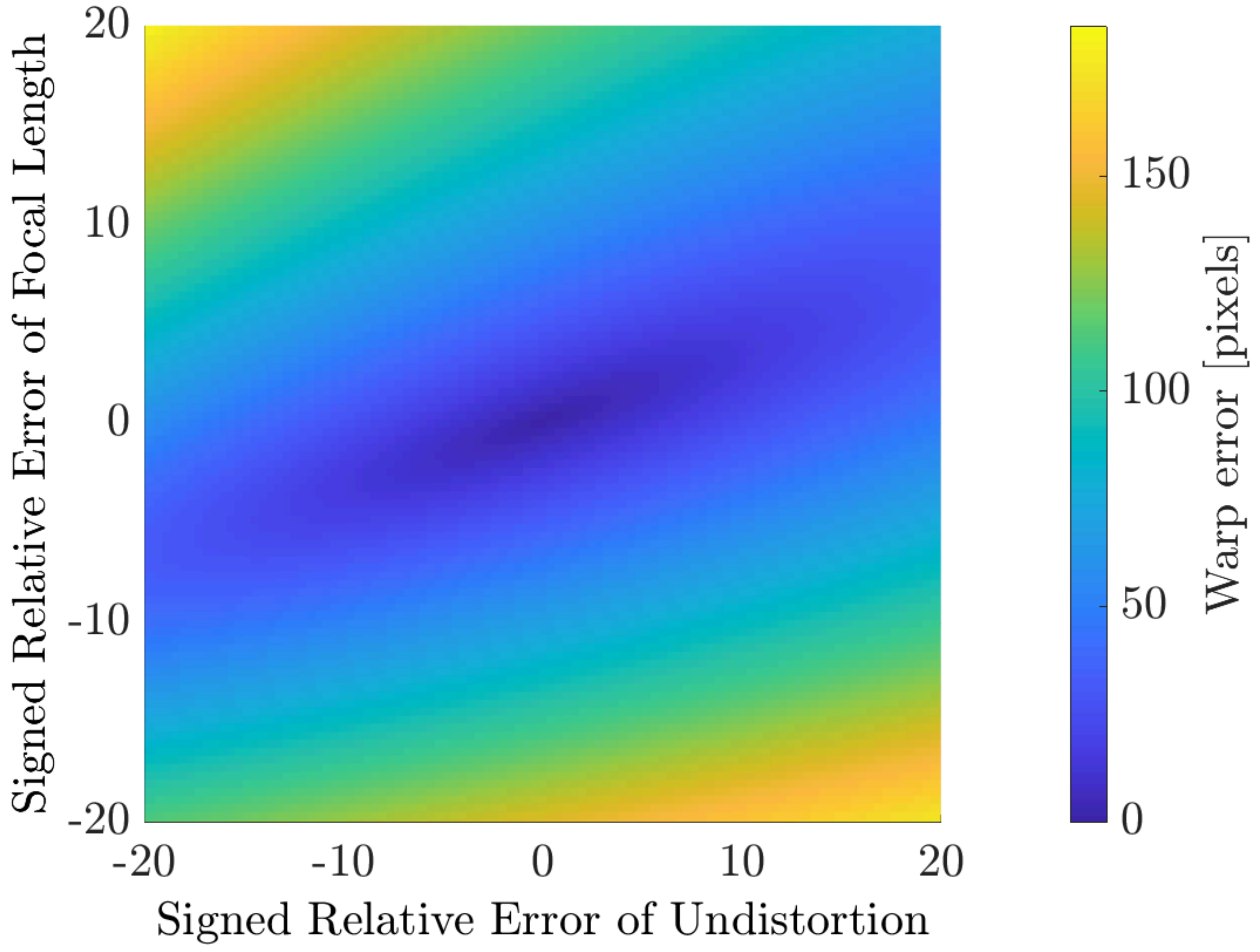


Warp Error

Geometric measure of calibration accuracy

$$d(\tilde{\mathbf{x}}_i, g^d(\hat{\mathrm{K}}\mathrm{K}^{-1} g(\tilde{\mathbf{x}}_i, \lambda), \hat{\lambda}))$$





Percentage of Top-1 Solutions

	Solver	% of Top-1
SOTA	**4PC (EVP)**	1.5%
	5CA	10.2%
Proposed	**4PC+2CA**	15.5%
	2PC+4CA	21.7%
	5CA*	25.4%
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Examples from AIT dataset

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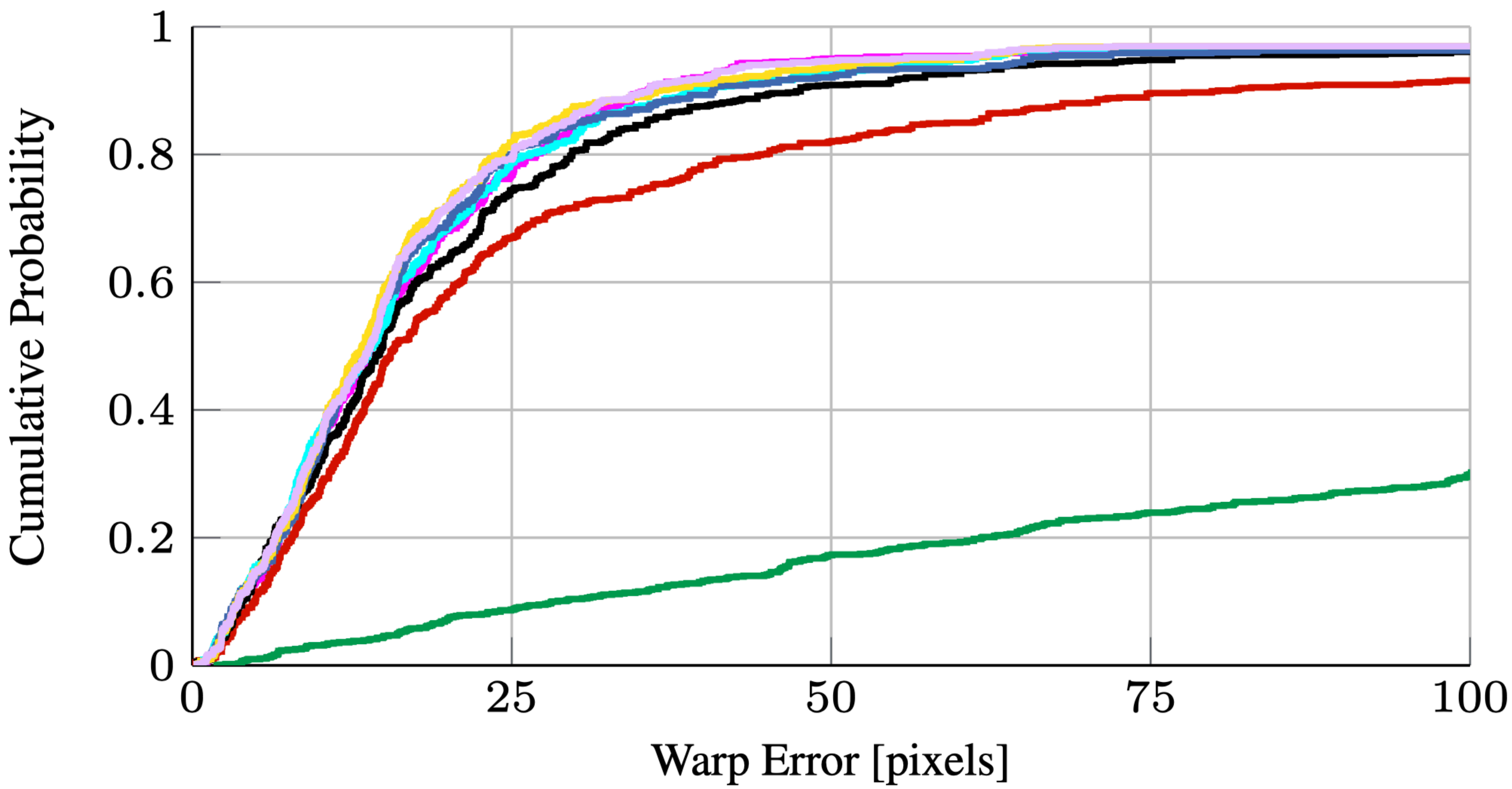
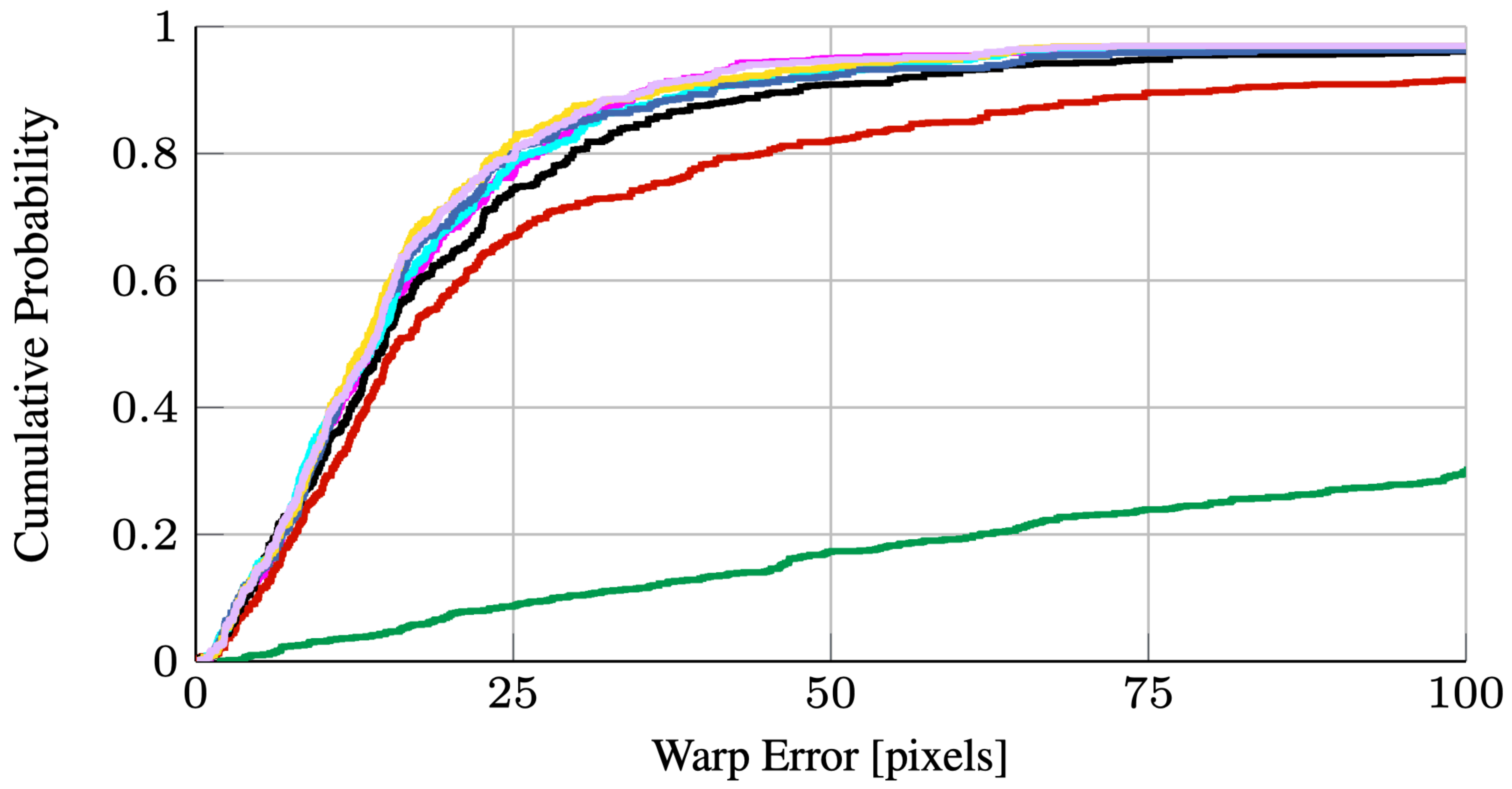
Performance on AIT dataset



Solver	Median RMS Warp Error
4PC (EVP)	186.51
5CA	14.02
4PC+2CA	15.86
2PC+4CA	14.9
5CA*	14.12
6CA	13.73
All	13.91
6CA & **2PC+4CA**	**13.35**

Performance on AIT dataset



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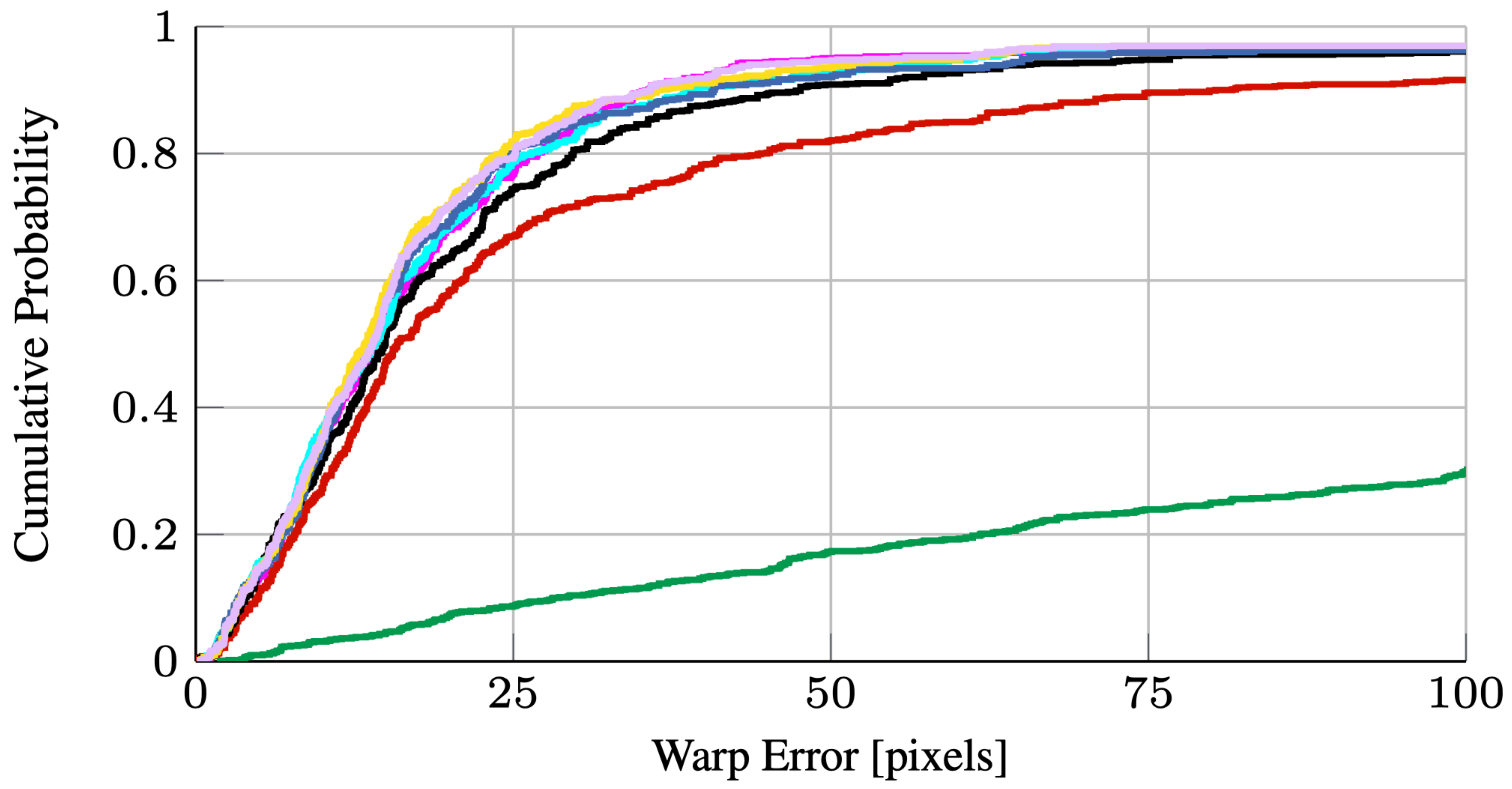
State-of-the-art

Performance on AIT dataset



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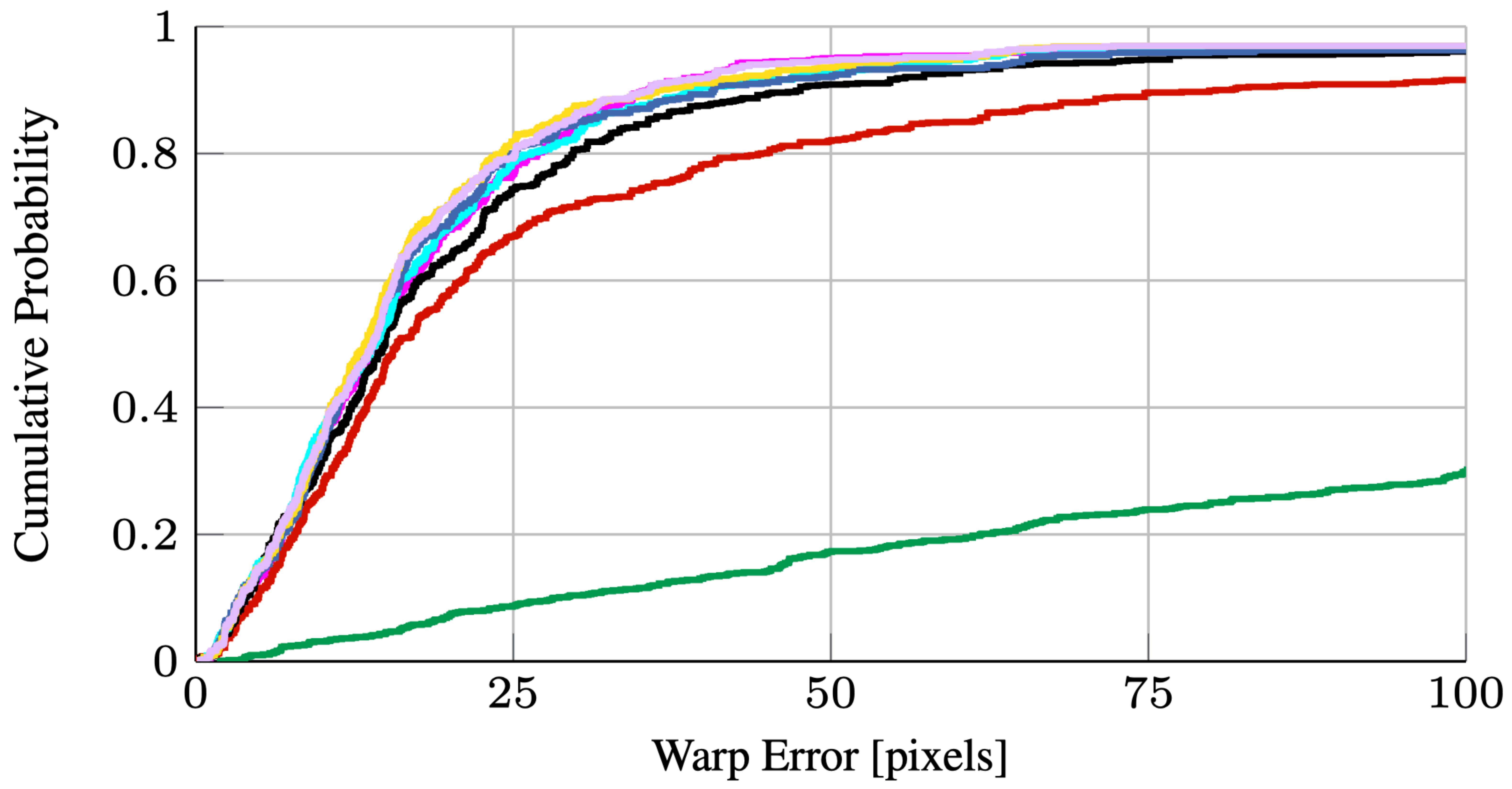
Proposed

Performance on AIT dataset



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Combinations

Future Directions

- Problem of noisy covariant regions — refine translational symmetries
- More accurate camera projection model via higher order distortion models
- Learn to conditionally sample the solvers in the hybrid RANSAC framework (based on the input, number of trials, best model so far etc)

arXiv

References

- Antunes et al. Unsupervised vanishing point detection and camera calibration from a single manhattan image with radial distortion. In *CVPR*, 2017
- Camposeco et al. Hybrid camera pose estimation. In *CVPR*, 2018
- Pritts et al. Minimal solvers for rectifying from radially-distorted conjugate translations. *IEEE TPAMI*, 2020
- Wildenauer et al. Closed form solution for radial distortion estimation from a single vanishing point. In *BMVC*, 2013