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Panoramic Mosaicing with a 180° Field of View Lens

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Outline

Talk overview:

- $> 180°$ FOV lens — FC-E8 description
- Spherical retina
- Mapping of light rays
- Complete camera model
- Procedure for computing the parameters of the model
- Experimental results
- Example of an application

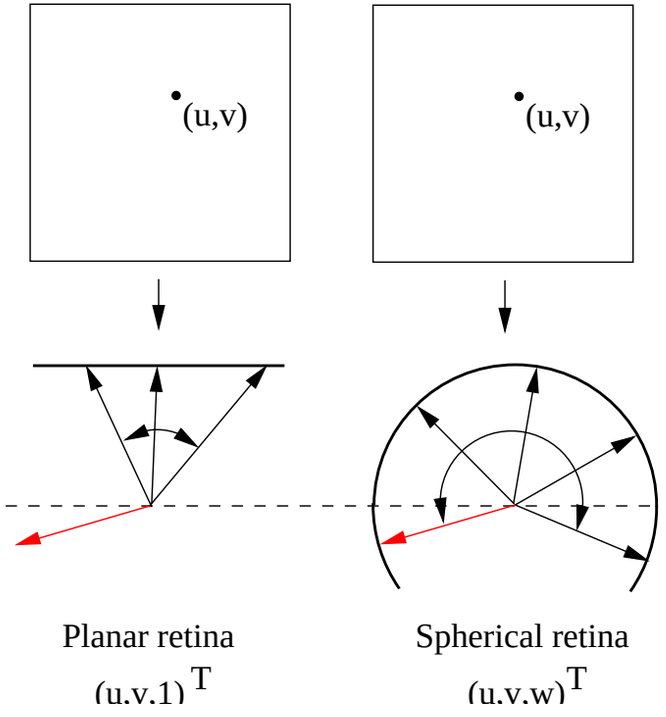
FC-E8 description

Specifications (source - Nikon)

Number of lenses	Five elements in four groups
Field of view	183°
Dimensions	ø74 mm x 50 mm
Weight	205 g

$> 180°$ **FOV** $\Rightarrow$ **spherical retina**

Traditional planar retina cannot be used for FOV $> 180°$

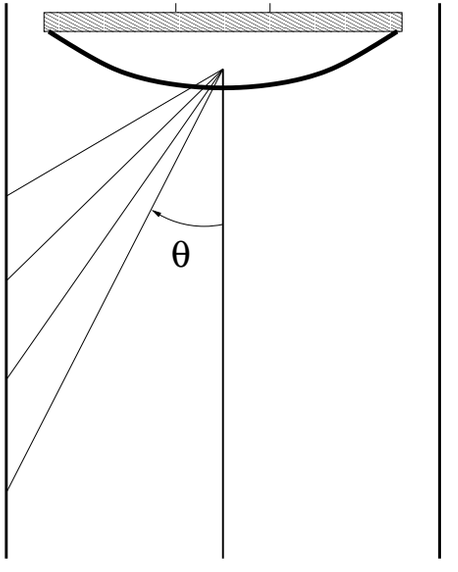


Spherical retina **must** be used for omnidirectional images

Mapping of the light rays

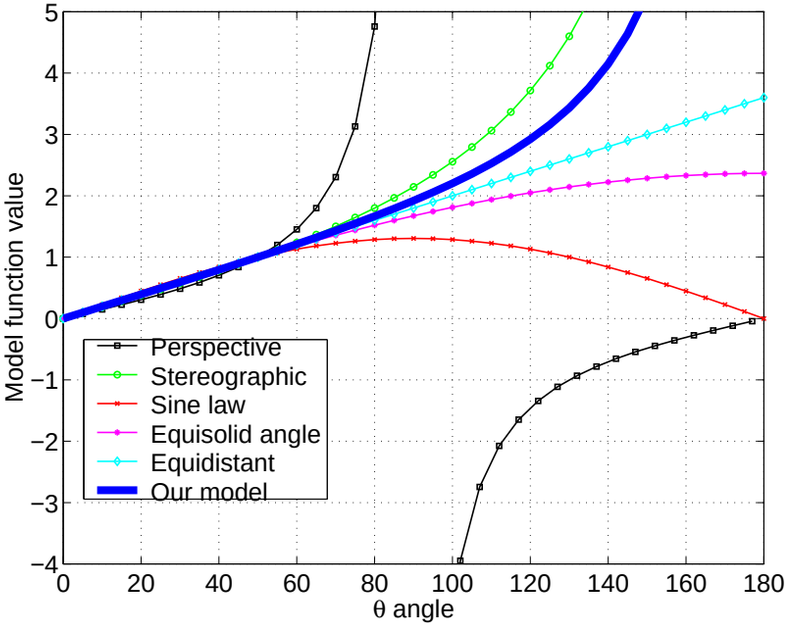
Projection models [Fleck, 1995]:

- perspective projection... $r = k \tan \theta$
- stereographic projection... $r = k \tan \frac{\theta}{2}$
- equidistant projection... $r = k\theta$
- equisolid angle projection... $r = k \sin \frac{\theta}{2}$
- sine law projection... $r = k \sin \theta$

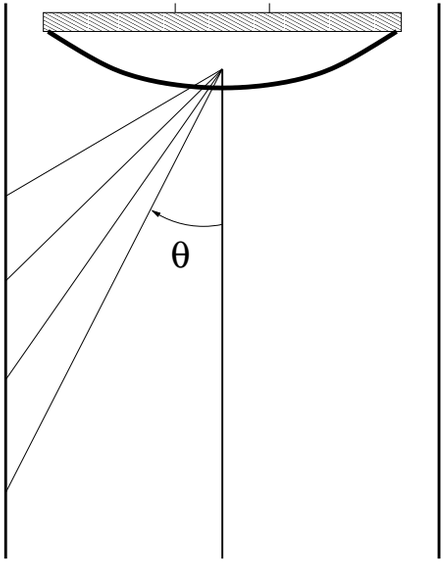


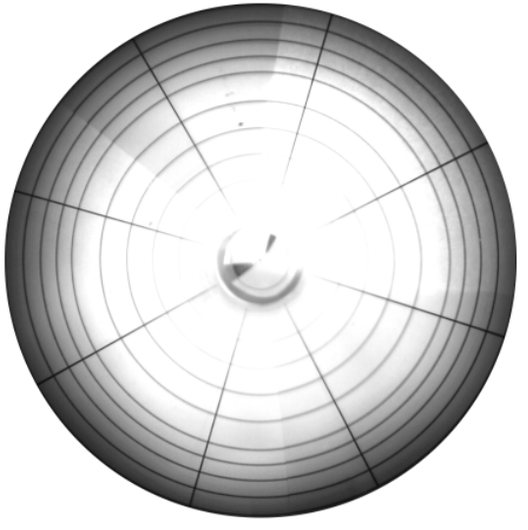
Model of the Nikon FC-E8:

$$r = a \tan \frac{\theta}{b} + c \sin \frac{\theta}{d}$$

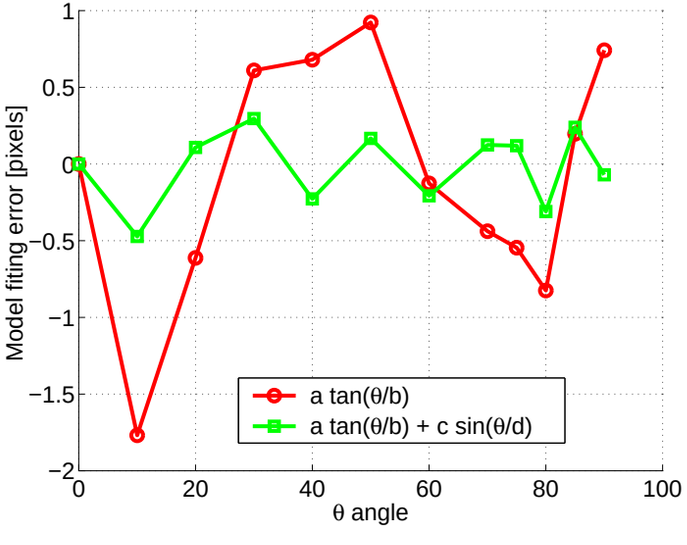


FC-E8 Internal structure determination





Experimental setup, known angle θ correspond to concentric circles in the image.



$$r = a \tan \frac{\theta}{b} + c \sin \frac{\theta}{d}$$

Model fit for stereographic projection and our function.

Complete model calibration

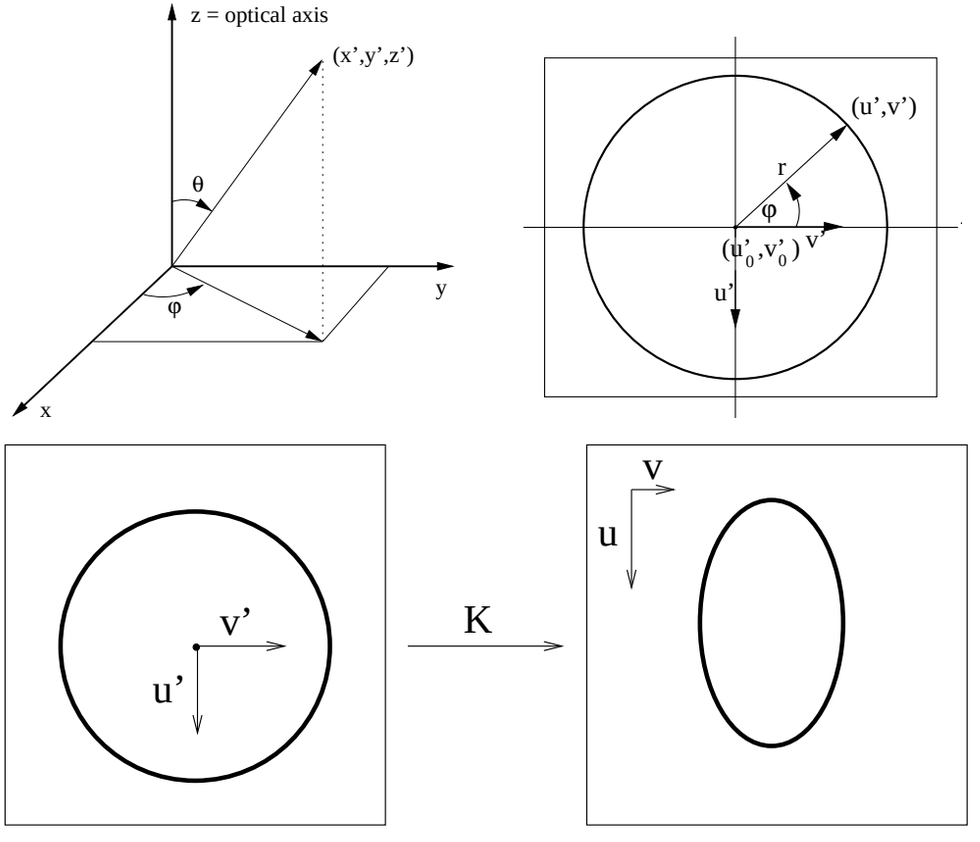
Extrinsic parameters

$$\tilde{\mathbf{X}} = \mathbf{R}\mathbf{X} + \mathbf{T}$$

Mapping of the light rays

$$r = a \tan\frac{\theta}{b} + c \sin\frac{\theta}{d}$$

$$u' = r\cos\varphi$$
$$v' = r\sin\varphi$$



Intrinsic parameters (zero skew)

$$\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & & u_0 \\ & \beta & \beta v_0 \\ & & 1 \end{pmatrix} \begin{pmatrix} u' \\ v' \\ 1 \end{pmatrix}$$

$$\mathbf{u} = \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & & u_0 \\ & \beta & \beta v_0 \\ & & 1 \end{pmatrix} \begin{pmatrix} r(\tilde{\mathbf{X}}, a, b, c, d)\cos\varphi(\tilde{\mathbf{X}}) \\ r(\tilde{\mathbf{X}}, a, b, c, d)\sin\varphi(\tilde{\mathbf{X}}) \\ 1 \end{pmatrix} \quad , \quad \tilde{\mathbf{X}} = \mathbf{R}\mathbf{X} + \mathbf{T}$$

Objective function

$$\mathbf{u} = \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & & u_0 \\ & \beta & \beta v_0 \\ & & 1 \end{pmatrix} \begin{pmatrix} r(\tilde{\mathbf{X}}, a, b, c, d) \cos \varphi(\tilde{\mathbf{X}}) \\ r(\tilde{\mathbf{X}}, a, b, c, d) \sin \varphi(\tilde{\mathbf{X}}) \\ 1 \end{pmatrix} \quad , \quad \tilde{\mathbf{X}} = \mathbf{R}\mathbf{X} + \mathbf{T}$$

Minimize the objective function J with respect to **13** parameters (**6** for extrinsic parameters $(\omega, \kappa, \rho, t_1, t_2, t_3)$, **4** identifying the model (a, b, c, d), β, and (u_0, v_0)):

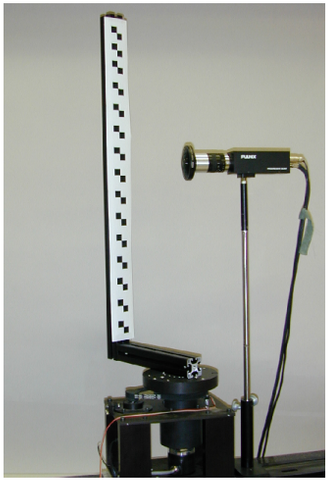
$$J_{(\omega,\kappa,\rho,t_1,t_2,t_3,a,b,c,d,\beta,u_0,v_0)} = \sum_{i=1}^{N} \left\| \tilde{\mathbf{u}} - \mathbf{u}_{(\omega,\kappa,\rho,t_1,t_2,t_3,a,b,c,d,\beta,u_0,v_0)} \right\| \quad ,$$

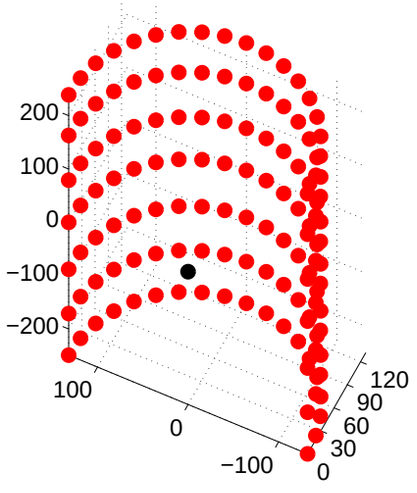
where $\mathbf{u}_{(\omega,\kappa,\rho,t_1,t_2,t_3,a,b,c,d,\beta,u_0,v_0)}$ represents the points reprojected by the model and $\tilde{\mathbf{u}}$ stands for the point coordinates measured in the image.

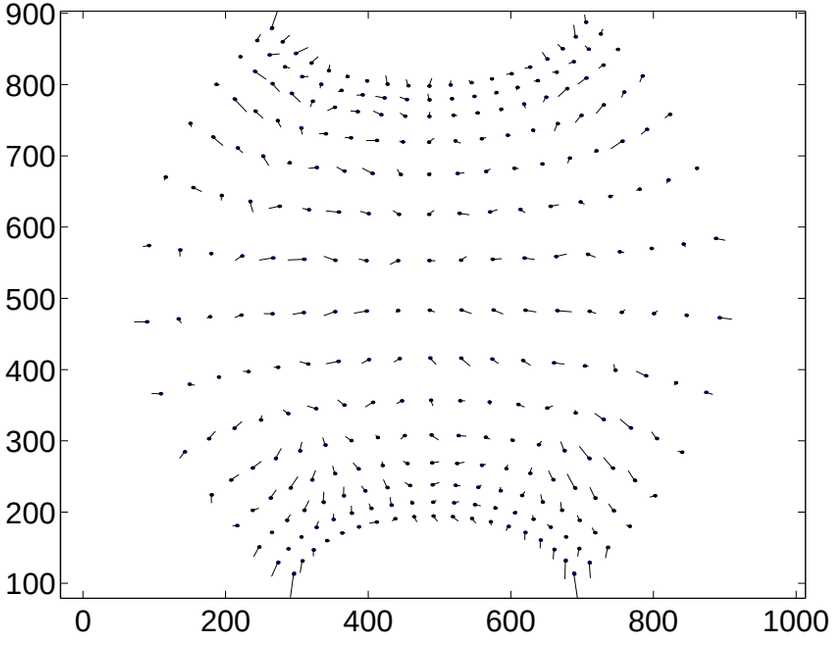
Objective function minimization

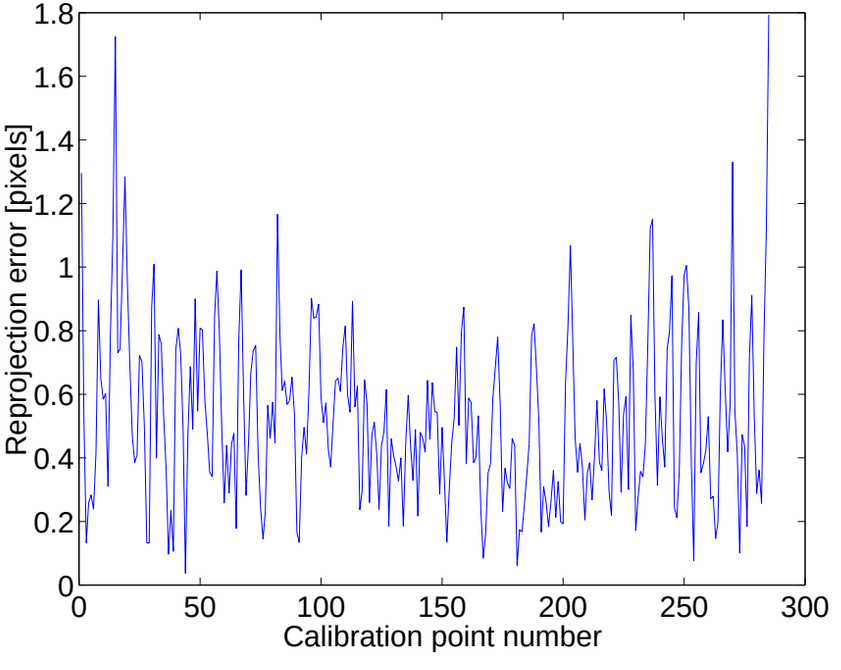
Development of the value of the objective function during optimization. The errors are scaled 20 times.

Experimental results





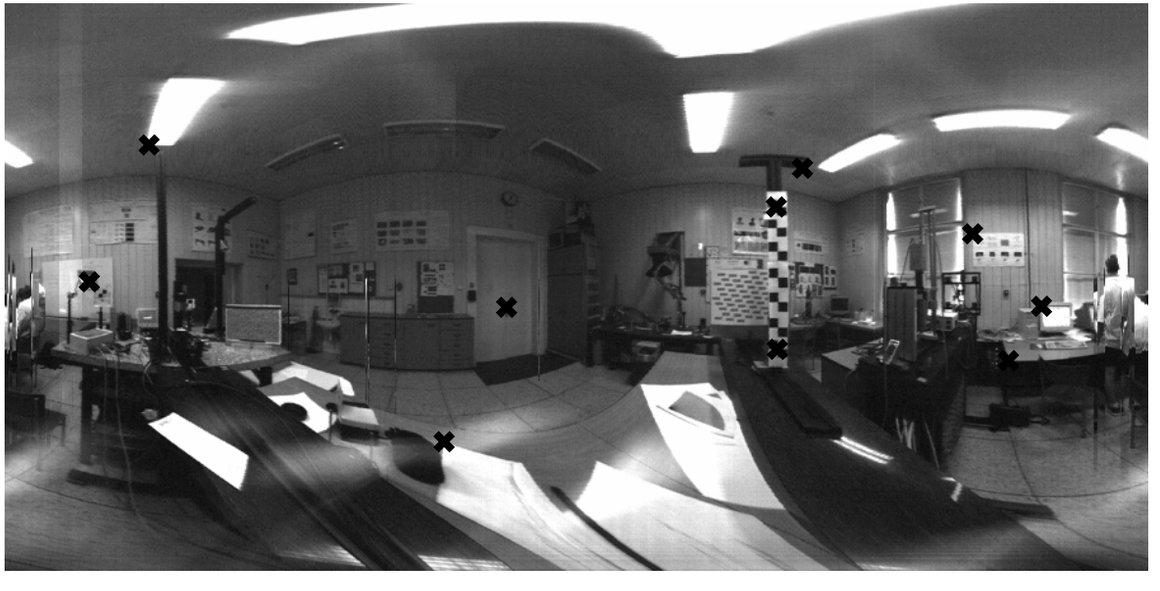




Experimental setup and the reprojection error (the value of the objective function J). The arrows representing the error are scaled 20 times.

An application - the 360 x 360 mosaic

- Conventional cameras have **limited FOV**
- 360 x 360 mosaic covers 360° in **both horizontal** and **vertical** direction



An application - the 360 x 360 mosaic

- they are realized by moving a planar pencil of light rays π on a circular path
- the pencil π can be realized used the Nikon FC-E8 fish eye converter

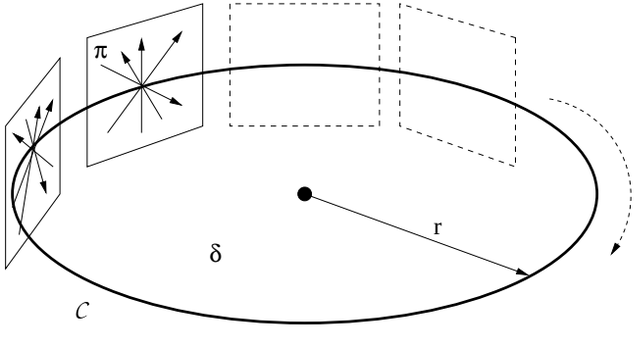
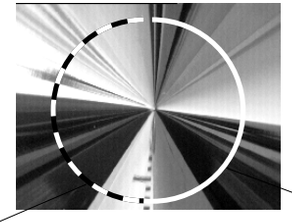
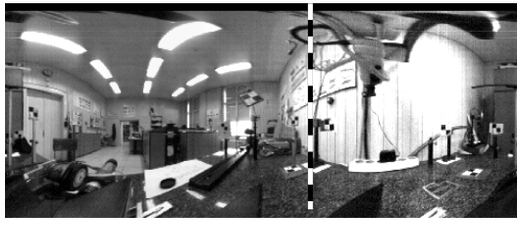
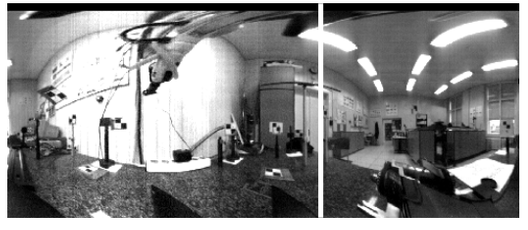


Image acquired by a CCD camera

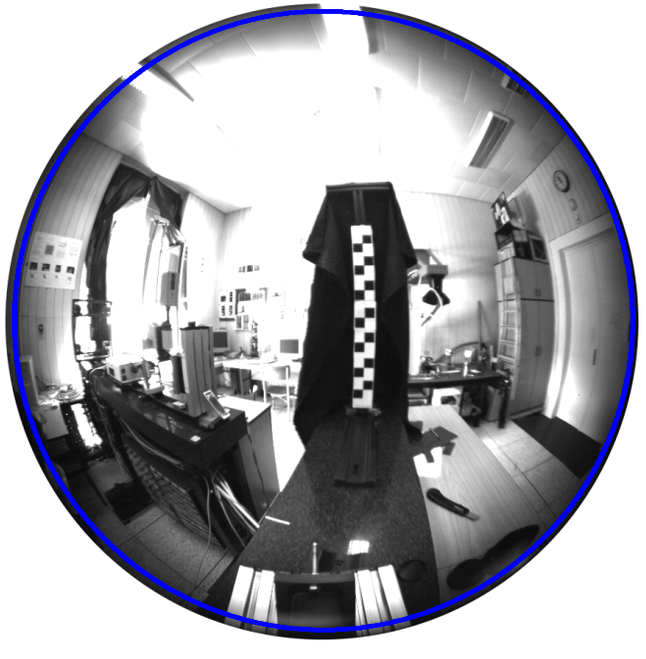




Left eye mosaic



Right eye mosaic

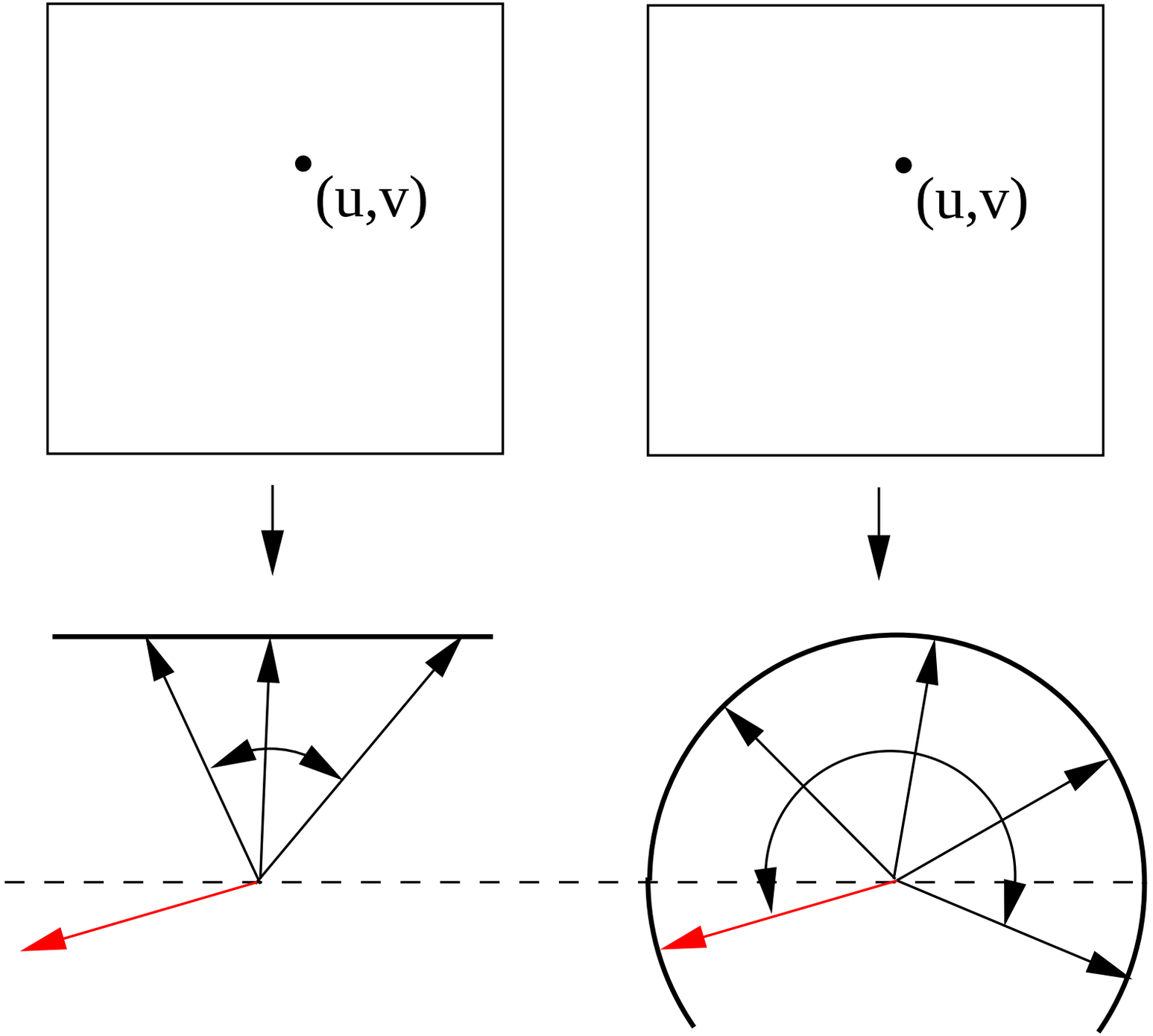


Conclusion

- Realization of the 360 x 360 mosaic with a fish eye lens was proposed.
- A model for the FC-E8 converter lens was derived.
- A calibration procedure was presented.


Nikon


PULNIX

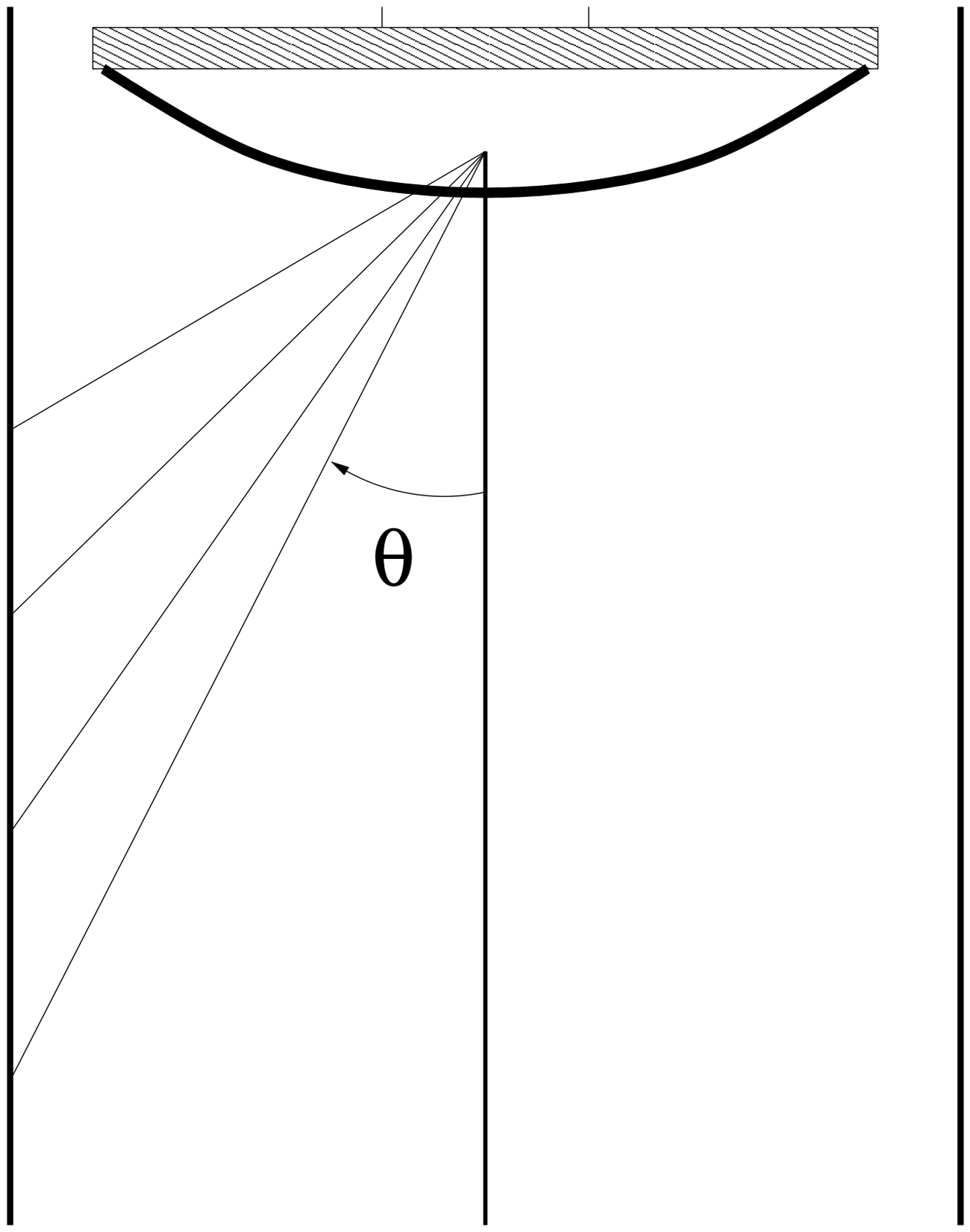


Planar retina

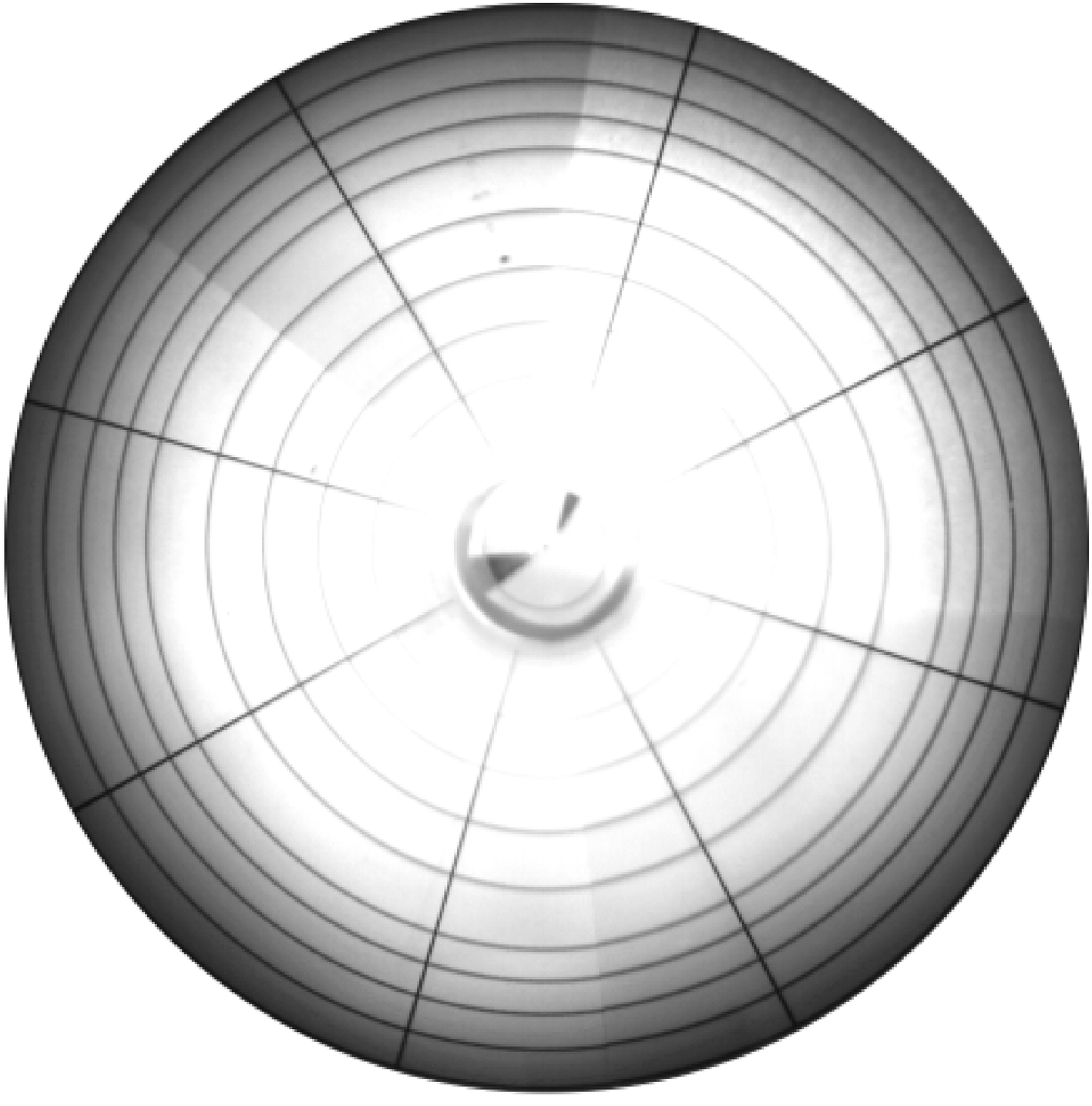
$(u,v,1)^T$

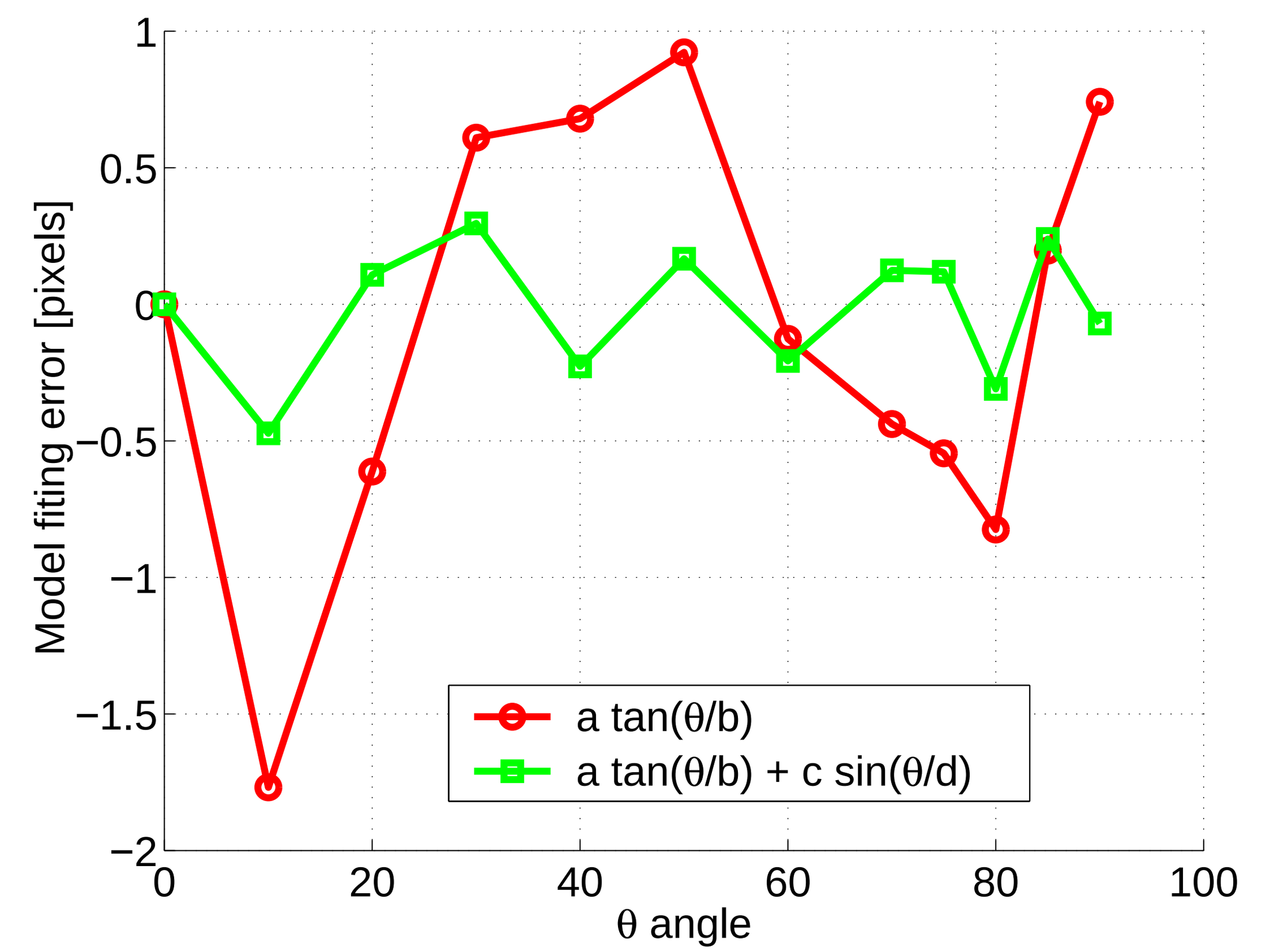
Spherical retina

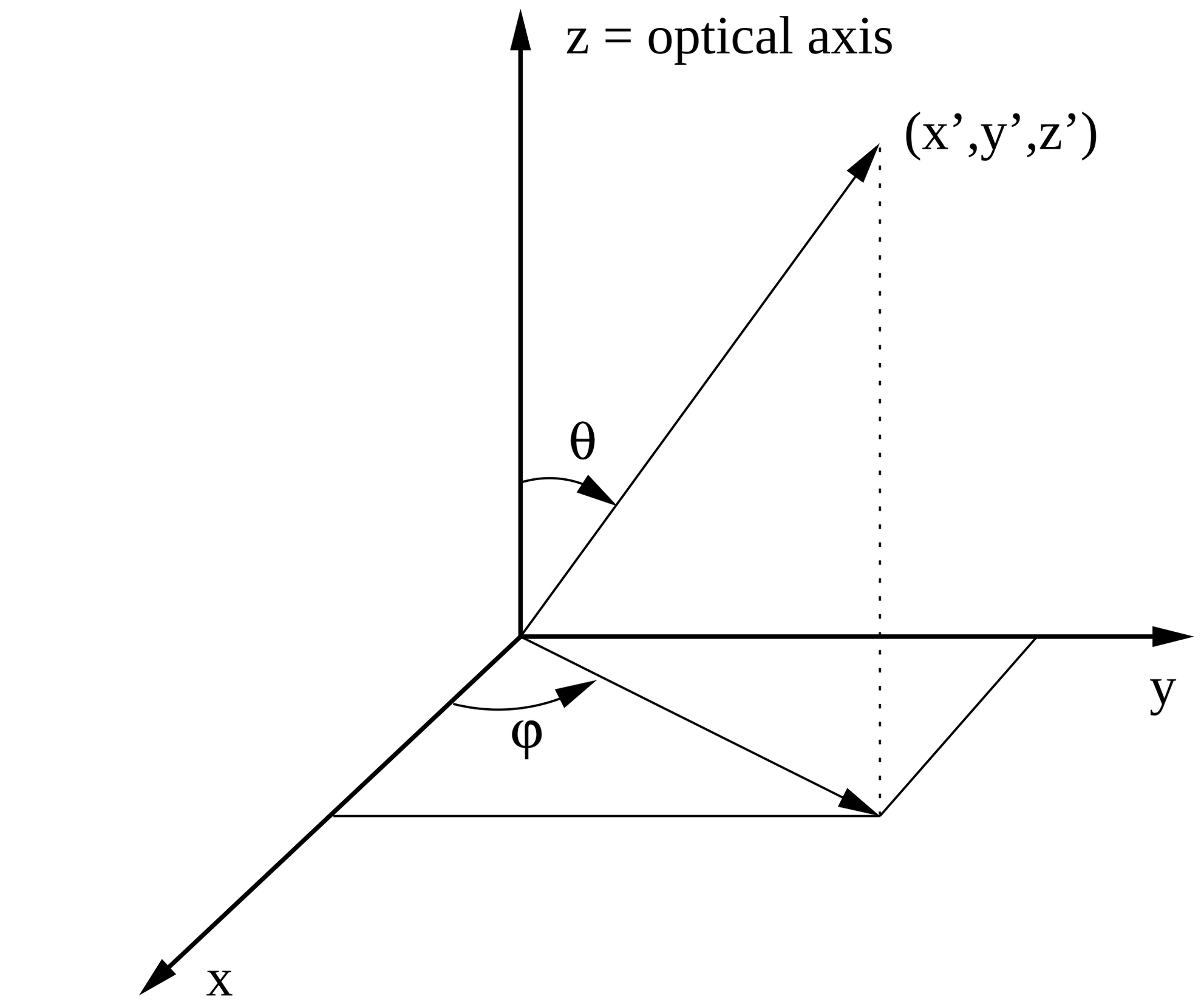
$(u,v,w)^T$

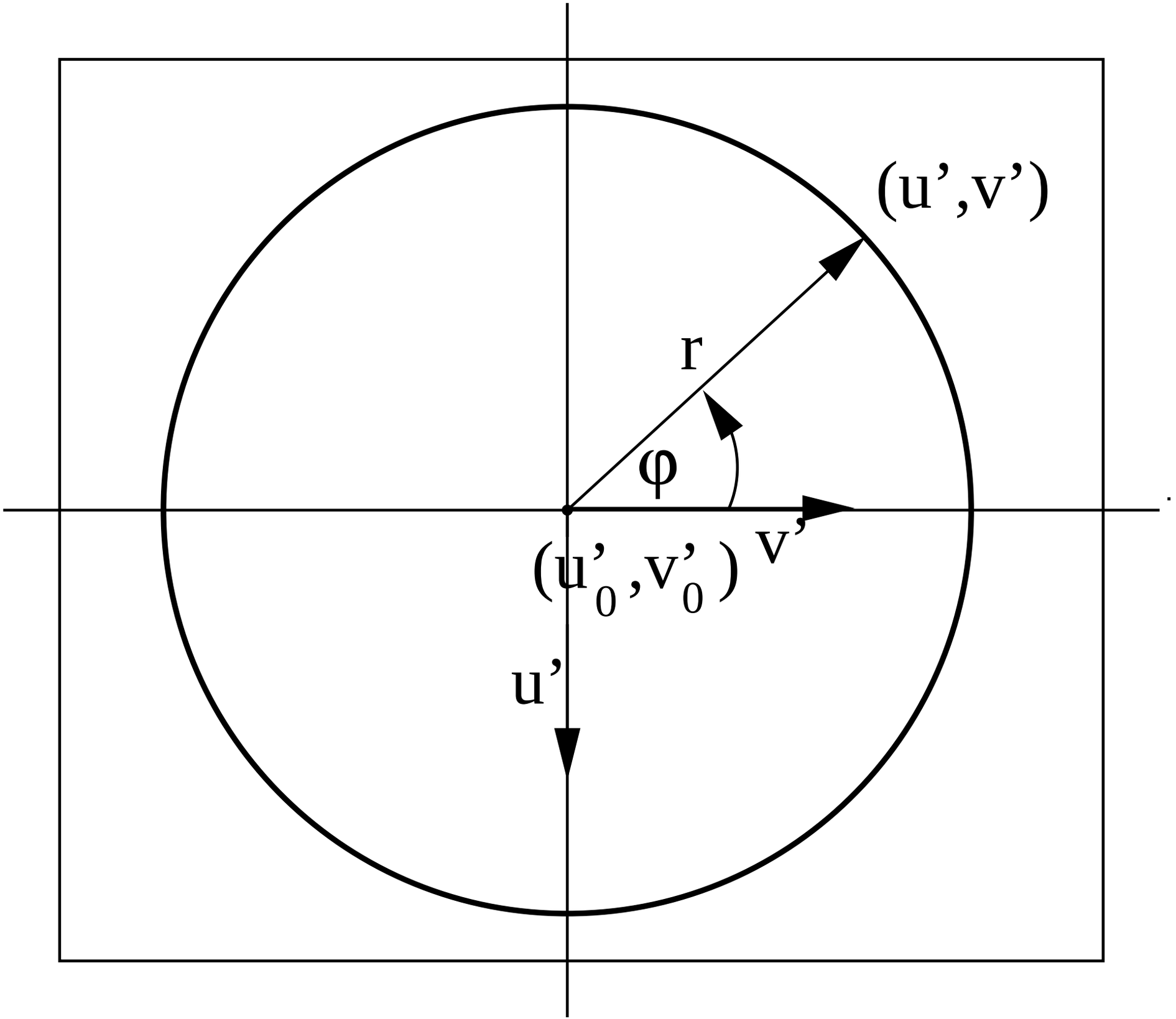

θ

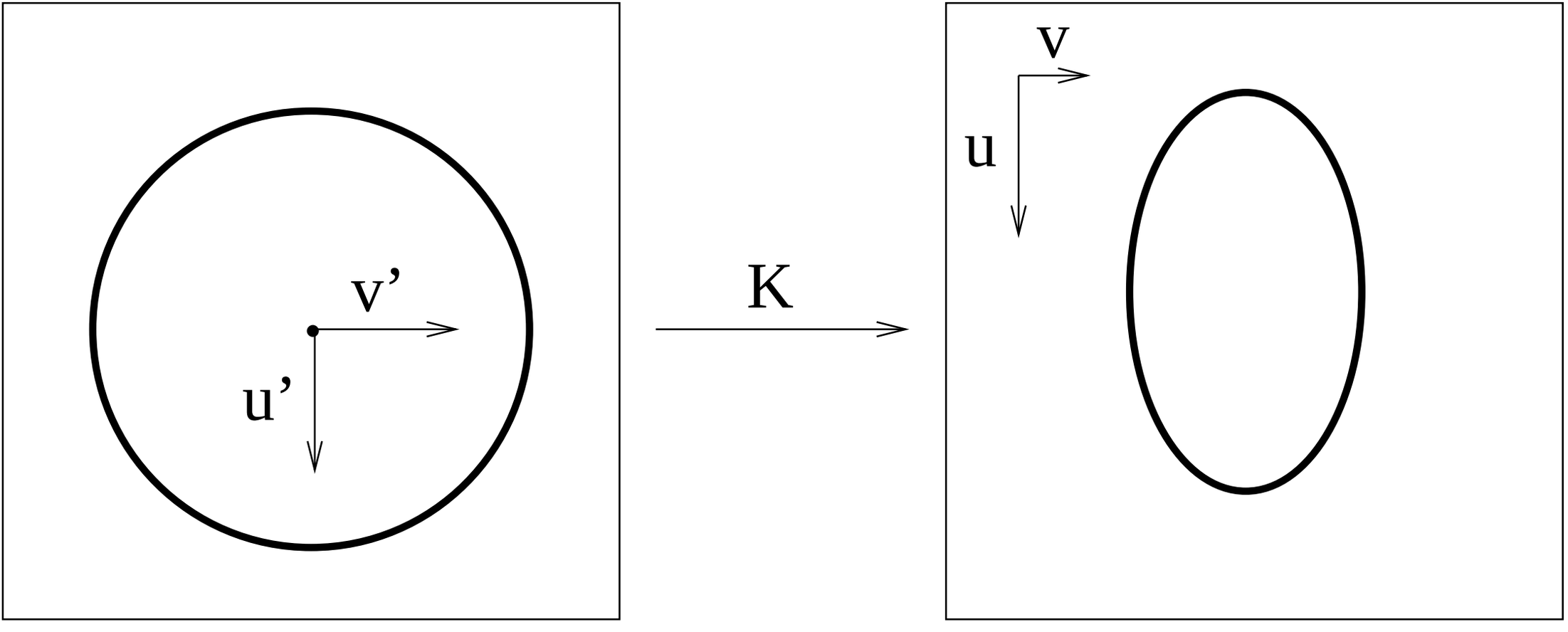

FUJINON
PROGRESSIVE SCAN

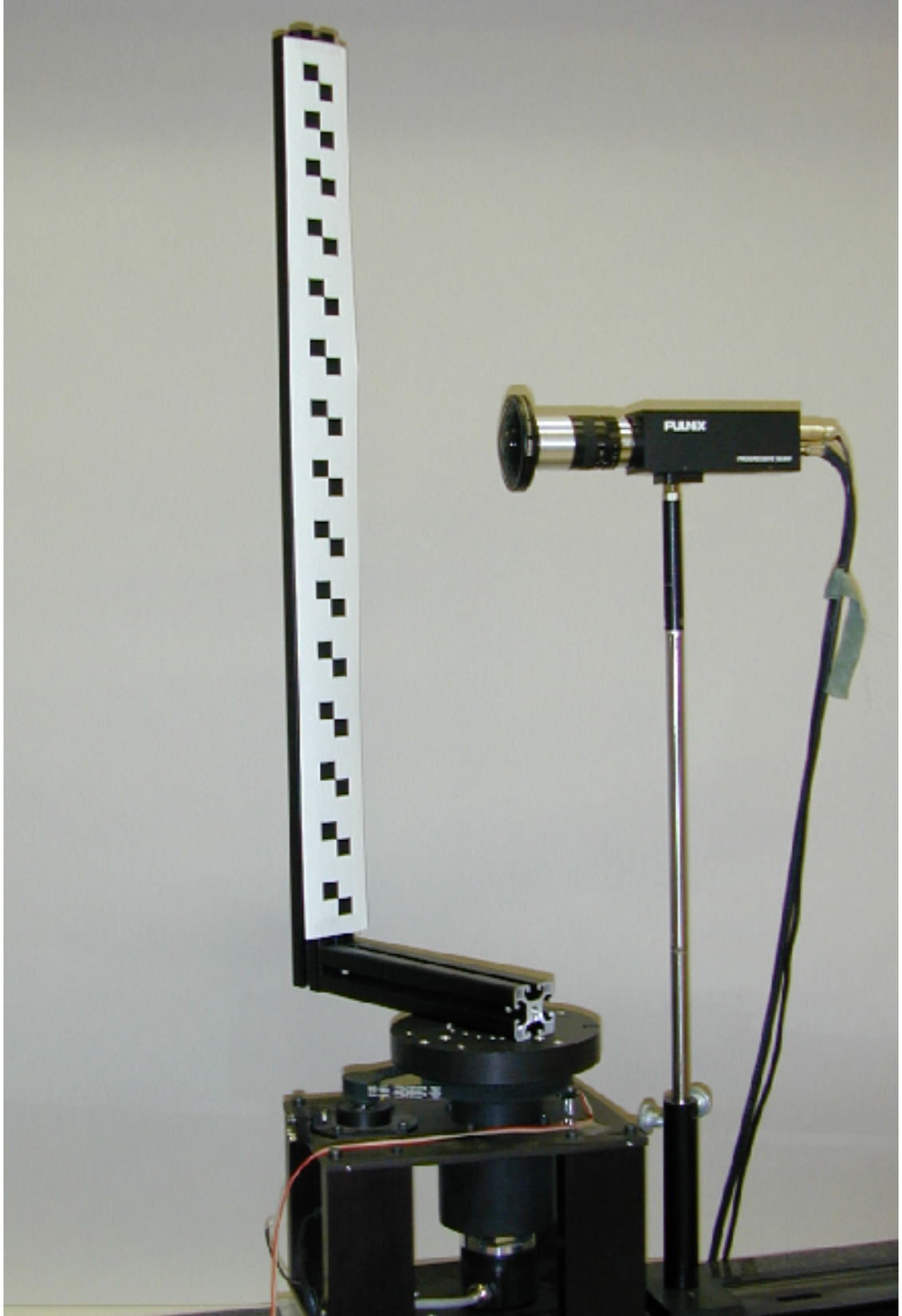


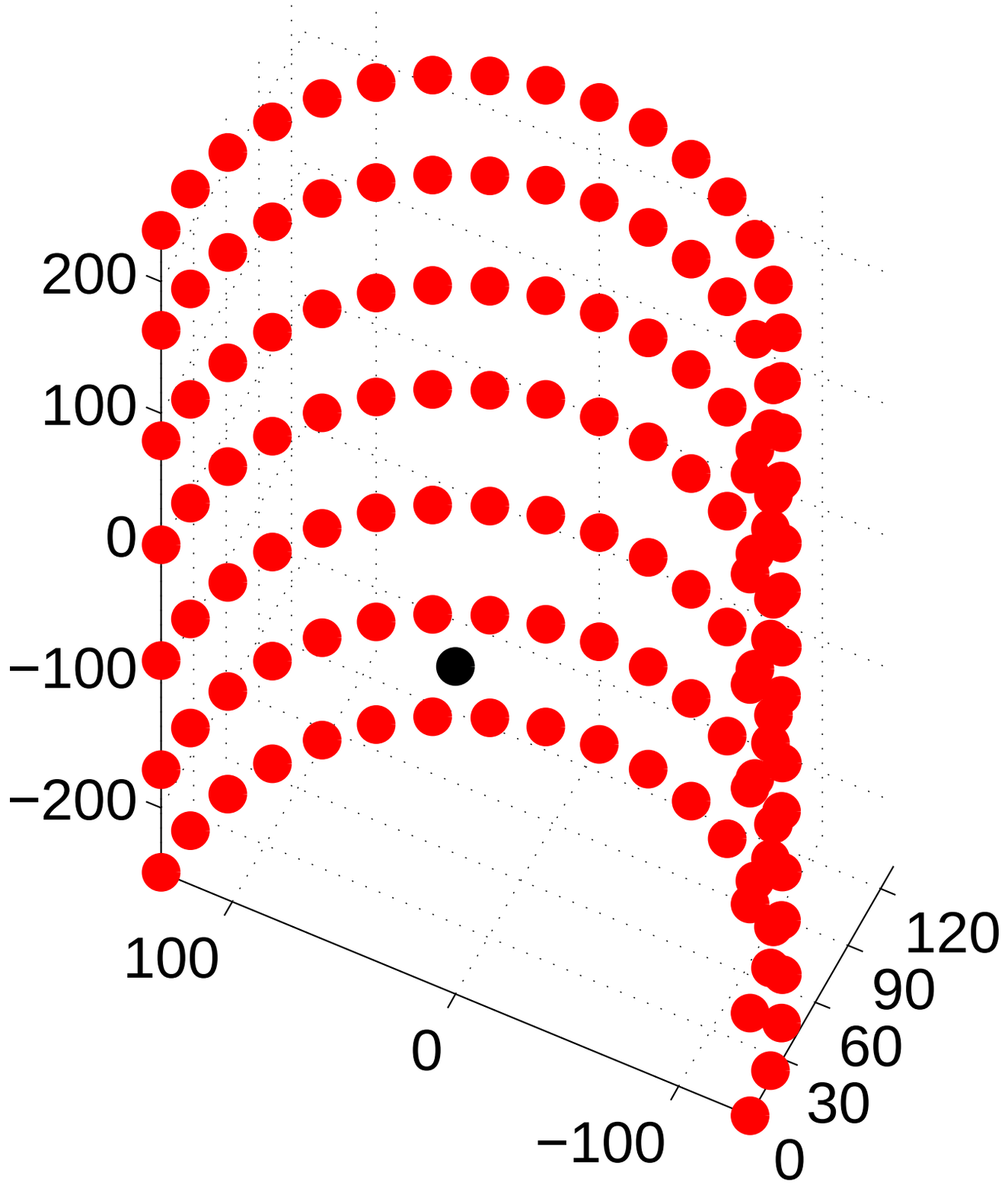

Model fiting error [pixels]
θ angle
a tan(θ/b)
a tan(θ/b) + c sin(θ/d)
1
0.5
0
−0.5
−1
−1.5
−2
0
20
40
60
80
100

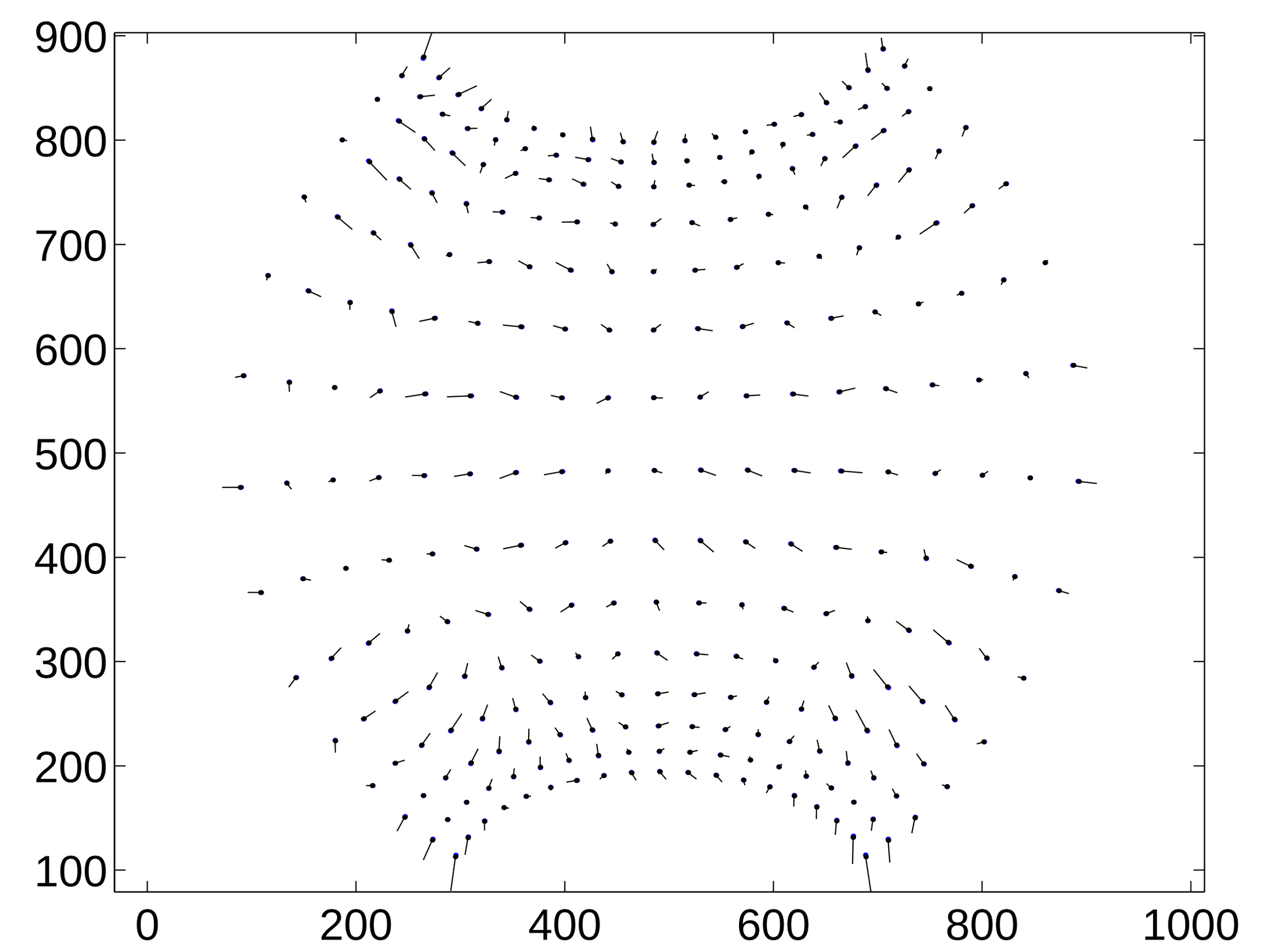

z = optical axis
(x’,y’,z’)
θ
φ
y
x

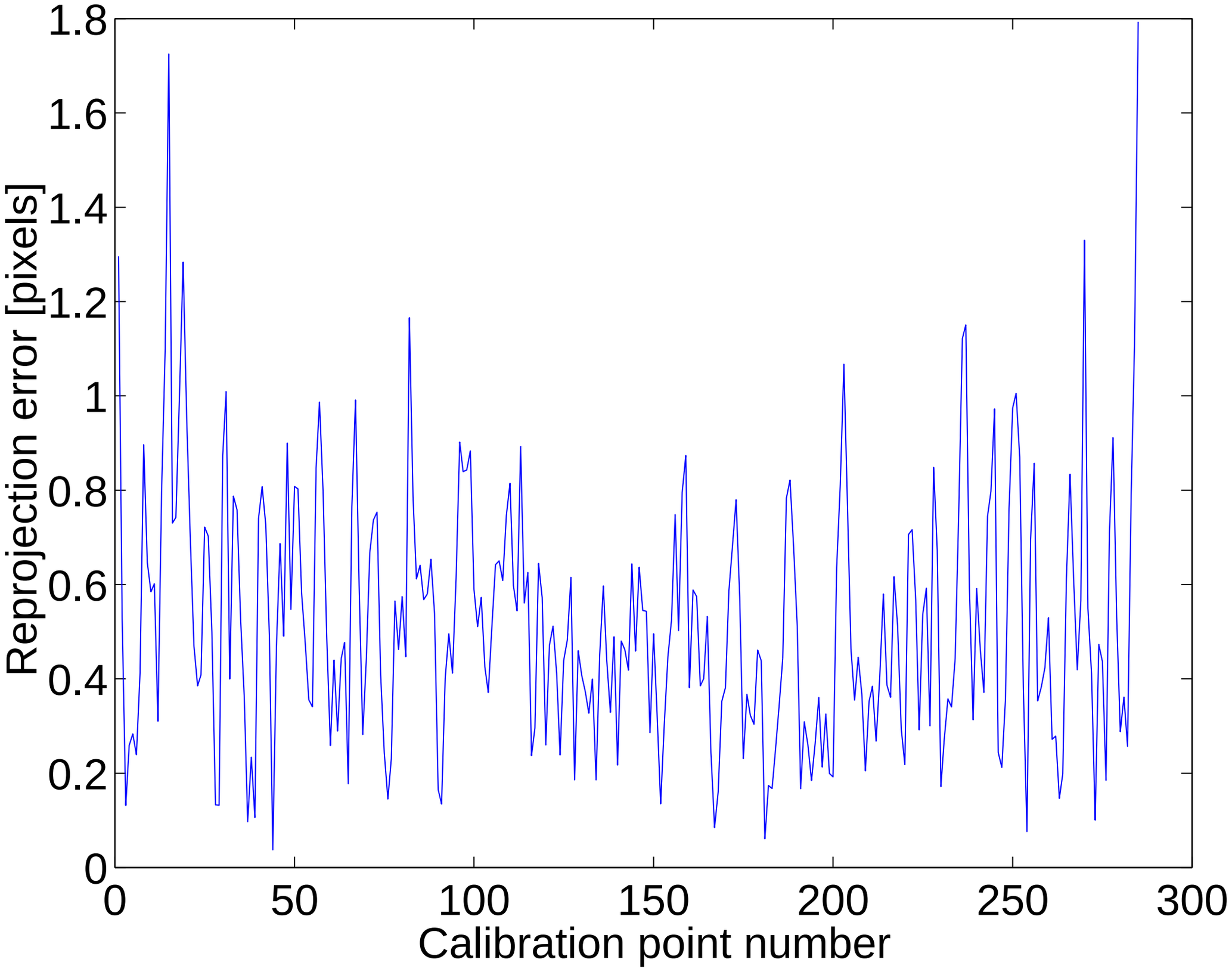

(u’,v’)
r
φ
(u’0,v’0)
v’
u’

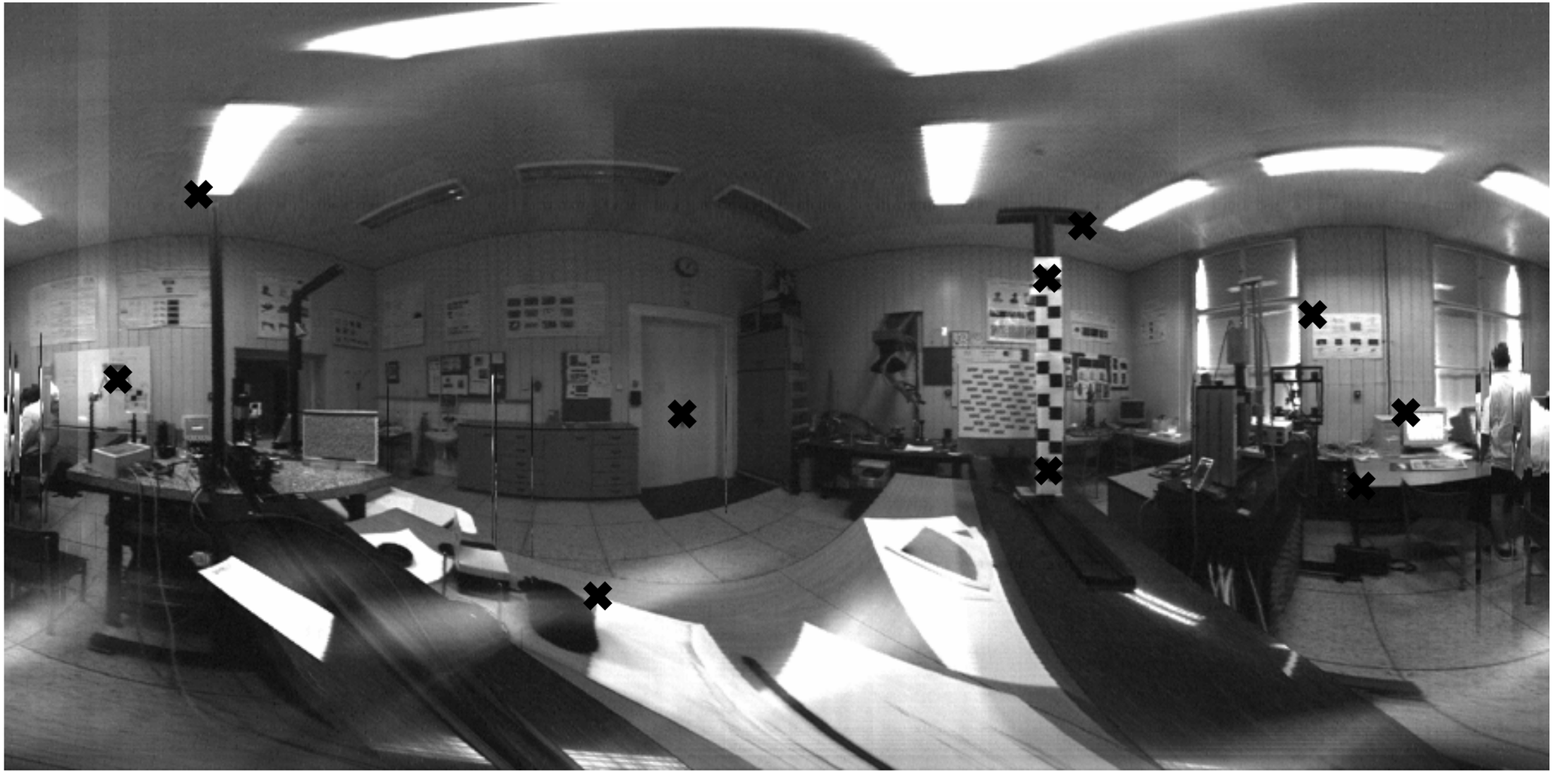

v'
u'
K
v
u


PUMX


200
100
0
−100
−200
100
0
−100
120
90
60
30
0


900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000


Reprojection error [pixels]
Calibration point number
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
50
100
150
200
250
300



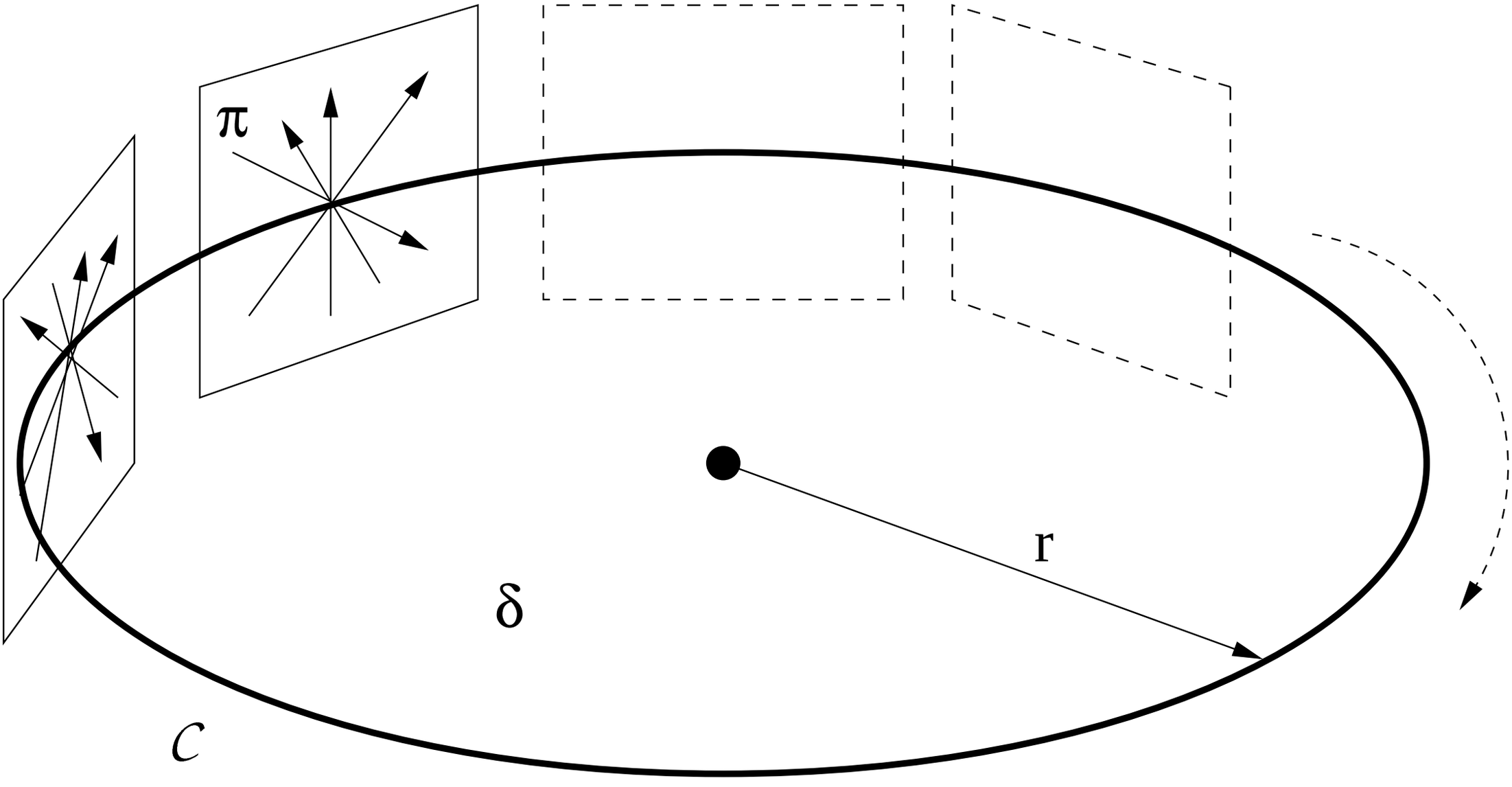
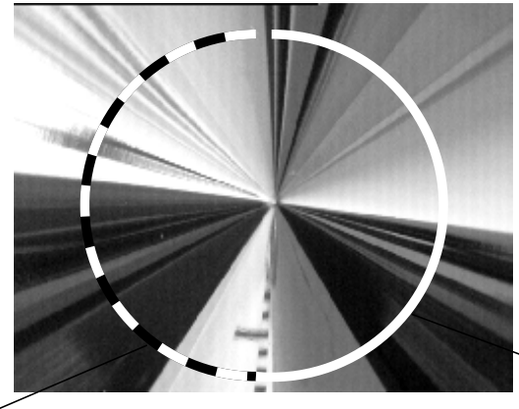
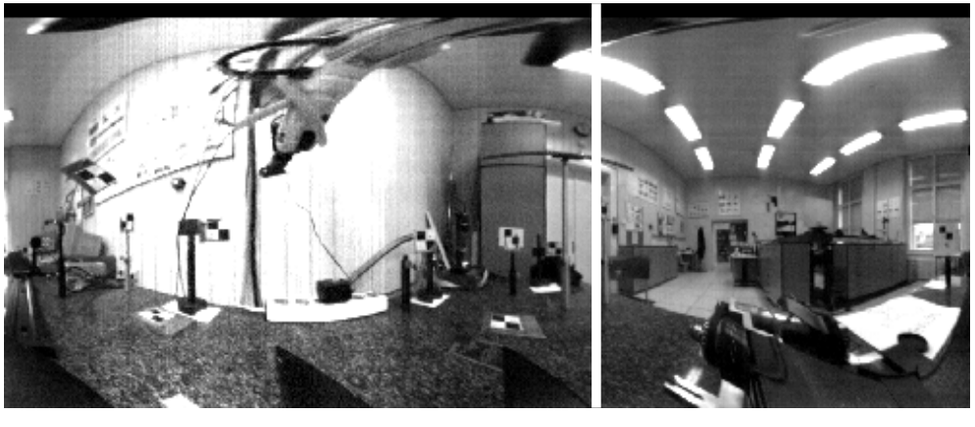

π
r
δ
C

Image acquired by a CCD camera





Left eye mosaic

Right eye mosaic