Motion Detection as an Application for the Omnidirectional Camera

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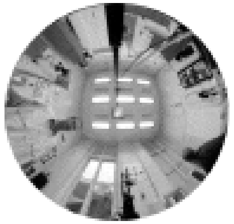
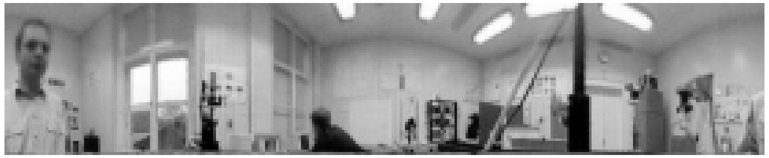
Outline
In surveillance applications with omnidirectional cameras it is necessary to transform the omnidirectional images into panoramic ones, which are more suitable for human inspection. This transformation is redundant when using a camera with a space variant imager, i.e. with a log-polar density (SVAVISCA). Hence the presentation shows in its first part the design of a new mirror shape that fits to the imager and in the second part its application as a motion detection sensor.

Omnidirectional Camera

Combination of a curved mirror and a camera.

Problem

- Mapping from polar to Cartesian coordinates.
- Image resolution is function of radius.

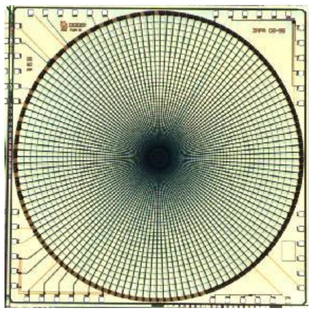
The omnidirectional camera is axially symmetric consequently the image in the image plane is best described by polar coordinates.

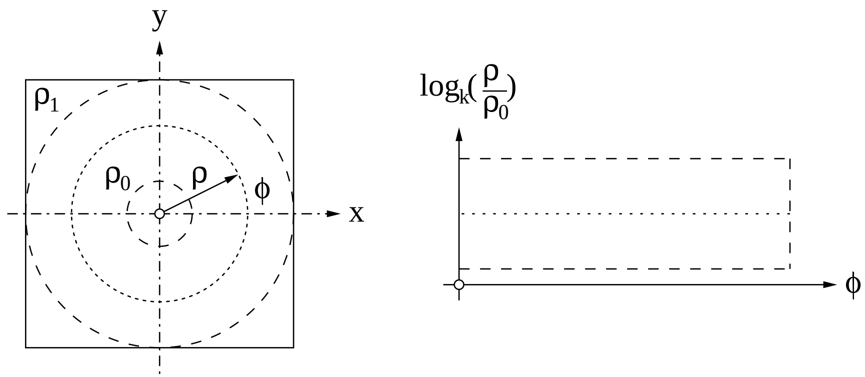
Solution

- Space variant imager.
- Mirror shape such that uniform image resolution results.

Space Variant Imager

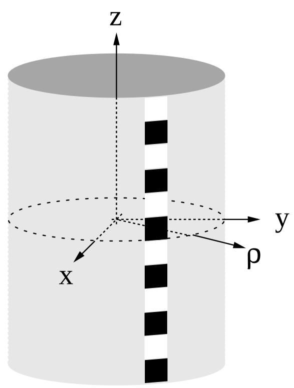
The imager has log-polar pixel distribution similar to the human retina receptor repartition.





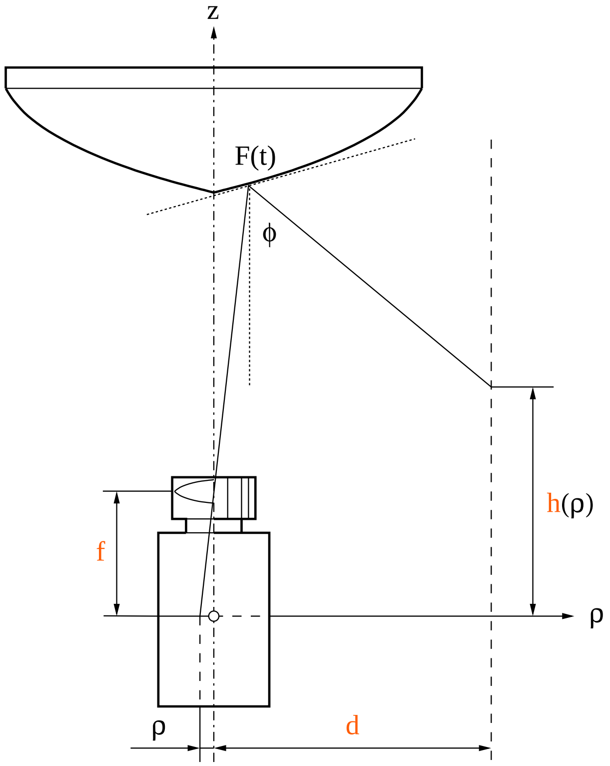
Projection

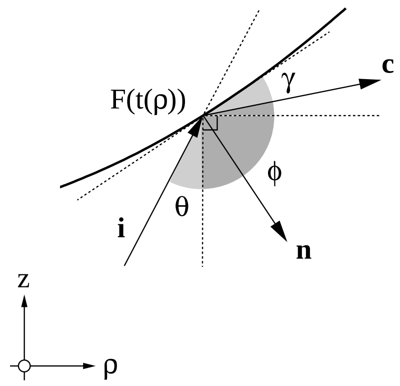
The image of objects forefront taken by the omnidirectional camera should have as uniform resolution as possible.



The mirror shape is given, when describing the problem by means of ray optics, in the form of a differential equation. Parameters to be designed are the desired *field of view* and the *cylinder radius*.

Cross Section Function





$$\boxed{-\vec{i}\cdot\vec{n} = \vec{n}\cdot\vec{c}}$$

The components of the vectors are as follows

$$\vec{i} = \frac{\vec{r}}{|\vec{r}|} = \left[\begin{array}{c} i_\rho \\ i_z \end{array}\right], \quad \vec{r} = \left[\begin{array}{c} t \\ F(t) - f \end{array}\right],$$

$$\vec{n} = \left[\begin{array}{c} \mathrm{d}F(t) \\ -\mathrm{d}t \end{array}\right], \qquad \vec{c} = \left[\begin{array}{c} c_\rho \\ c_z \end{array}\right].$$

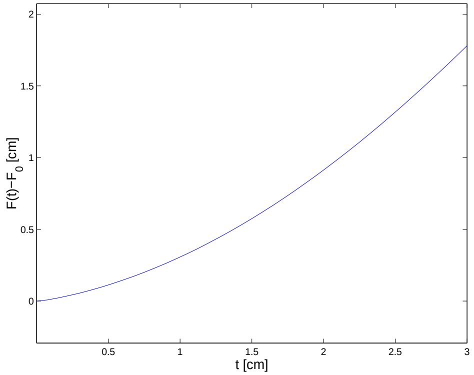
Cross Section Function

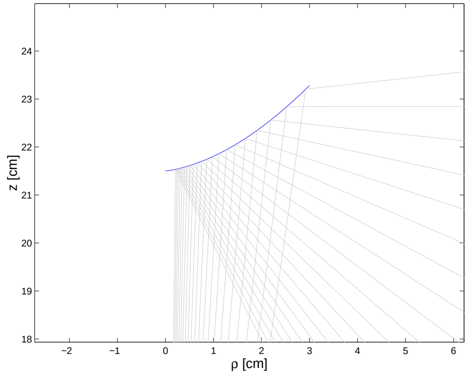
$$F'(t)^2 + 2\frac{t(d-t) + (F(t)-f)(F(t)-h(t))}{(F(t)-f)(d-t) - t(F(t)-h(t))}F'(t) - 1 = 0$$

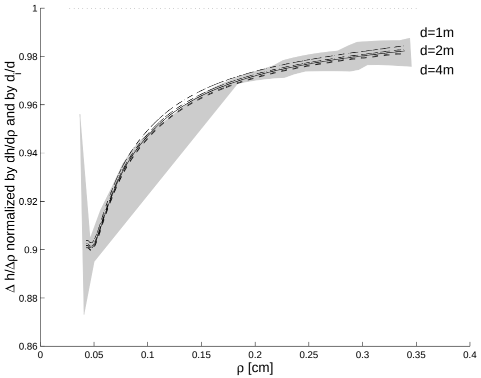
$$h(\rho) = a\log_k\left(\frac{\rho}{\rho_0}\right) + b \text{ ,where } \rho = \frac{ft}{F(t)-f}$$

A numerical approximation results as a solution for the cross section function.

Cross Section Function





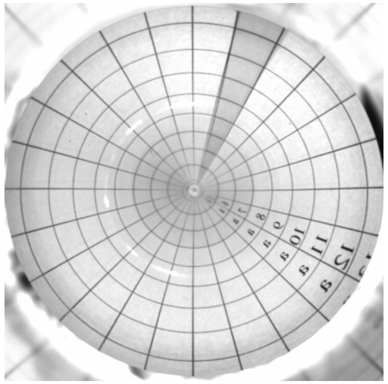


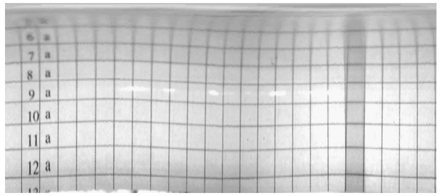
Field of view: $69.5°$ Cylinder radius: $d = 2$m

Conclusion

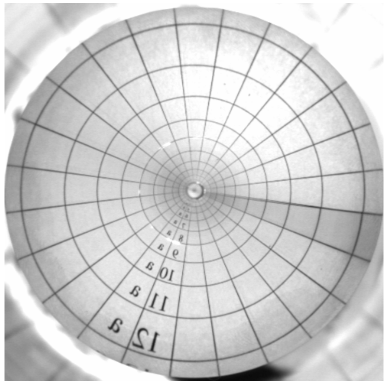
- The mirror maps approximately uniformly in the vertical dimension.
- The solution has a systematic error.
- The resulting omnidirectional camera has approximately perspective projection.

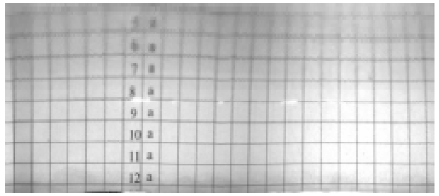
(a)





(b)





(a) Mirror for uniform resolution and common imager.

(b) Mirror for uniform resolution and SVAVISCA imager.

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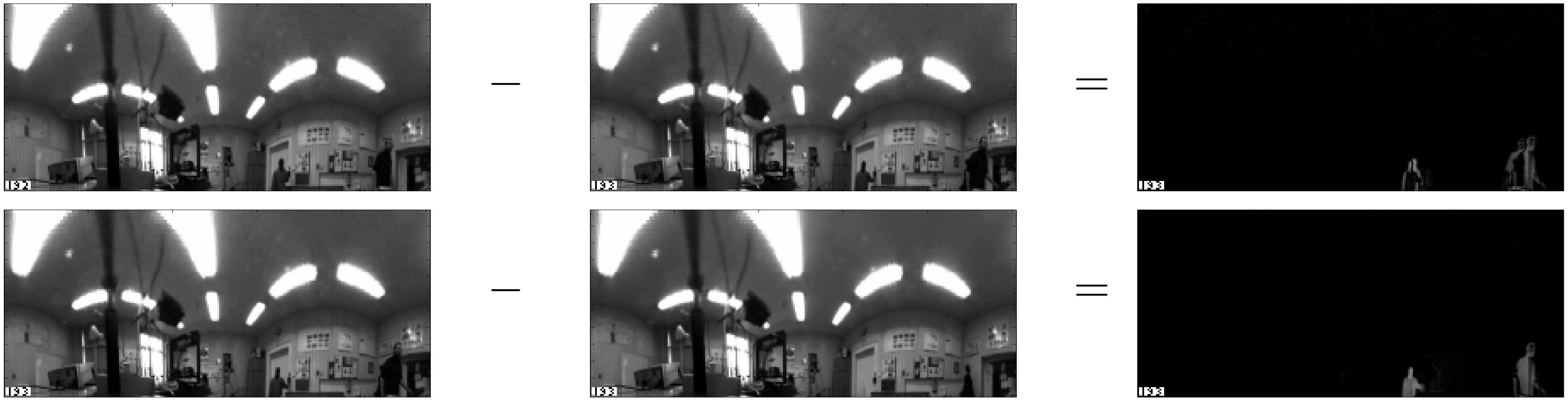
Motion Detection

Motion detection in an image sequence $f_0, \ldots, f_{i-1}, f_i$ by

- comparing consecutive images.
- comparing with background model.



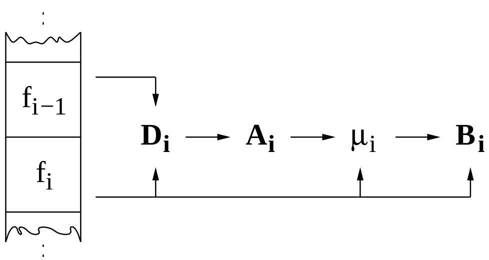
The application is a motion detection in an indoor scene. Moving persons, moving and moved objects and varying illumination can be expected.

Motion detection by comparing with background model is done by taking the difference between a current image f_i and the mean background image μ_i.

Problem
The background is changing over time and thus its model must be adapted using the current images. Therefore the distinction is necessary between foreground and background objects.

Criterion
How long an object has been stationary.

1. Temporal Change Detection $\mathcal{D}_i$
2. Temporal Change History $\mathcal{A}_i$
3. Background Model μ_i
4. Background Change Detection $\mathcal{B}_i$



Weighted Accumulation

The weighted accumulation is a moving average with a constant adaption length.

$$\begin{aligned}\hat{f}_i(m,n) &= \psi(\hat{f}_{i-1}, f_i, \tau, \mathcal{R})(m,n) \\ &= \hat{f}_{i-1}(m,n)\mathrm{e}^{-\frac{1}{\tau}} + f_i(m,n)(1-\mathrm{e}^{-\frac{1}{\tau}}) \quad ; \quad (m,n) \in \mathcal{R}\end{aligned}$$

$\hat{f}_i, \hat{f}_{i-1}$	mean image
f_i	current image
τ	accumulation length
$\mathcal{R}$	accumulation region

- Temporal Change Detection: Transforms moving contours into moving shapes.
- Background Change Detection: Adaption of the Background Model

Temporal Change Detection

The temporal change region $\mathcal{D}_i$ discerns between moving and stationary objects.

$$\mathcal{D}_i = \{(m,n) \in \mathcal{I} \mid d_i(m,n) > \varepsilon_d\}$$

$$d_i = \psi(d_{i-1}, |\delta f_i|, \tau_d, \mathcal{I}) \text{ ,where } |\delta f_i| = |f_i - f_{i-1}|$$

1. The accumulation length τ_d describes the temporal range for averaging of the absolute difference images $|\delta f_i|$.

2. The threshold ε_d controls the sensitivity to identify the temporal change region $\mathcal{D}_i$.

Temporal Change History

The adaption region $\mathcal{A}_i$ defines the region that did not change for a period of time.

$$\mathcal{A}_i = \mathcal{I} \setminus \bigcup_{k=\max(0,i-\eta)}^{i} \mathcal{D}_k$$

3. The adaption depth η weights how long a region in an image sequence is considered as a moving object.

The background change region $\mathcal{B}_i$ discerns between foreground and background objects.

$$\mathcal{B}_i = \{(m,n) \in \mathcal{I} \mid |\mu_i(m,n) - f_i(m,n)| > \varepsilon_b\}$$

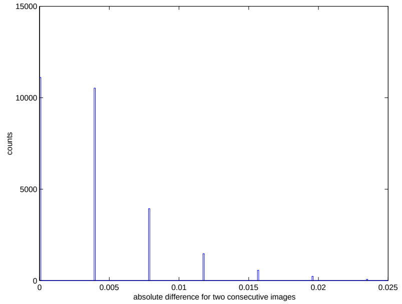
$$\mu_i = \psi(\mu_{i-1}, f_i, \tau_b, \mathcal{A}_i)$$

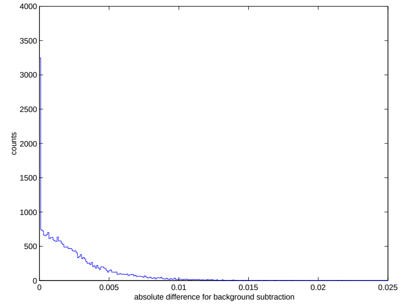
4. The adaption length τ_b describes the temporal range for background adaption in the adaption region $\mathcal{A}_i$.

5. The threshold ε_b controls the sensitivity to identify the background change region $\mathcal{B}_i$.

Thresholds

The thresholds ε_d and ε_b for the change detection are proportional to the noise in the difference images.





For the absolute difference a_i the noise is modelled by the positive values of the normal distribution $2N(0, 2\sigma^2)$. The standard deviation σ is estimated with the Least Median of Squares $\sigma = a_{\mathrm{LMS}}/0.3372$.

Assuming a probability of $1‰$ for incorrectly classifying an image point when the threshold is given by

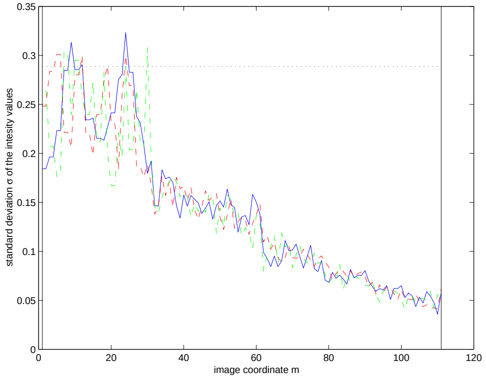
$$\varepsilon = \varepsilon_{\min} + \frac{2.576}{0.3372}\, a_{\mathrm{LMS}}$$

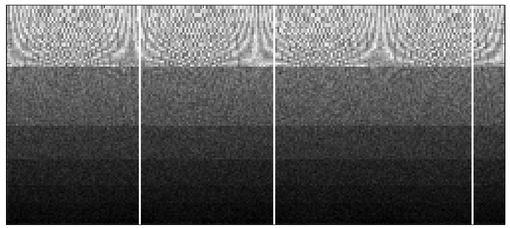
Noise Repartition

The image sequence consists of panoramic images obtained by resampling the omnidirectional images according to the pattern of the SVAVISCA imager.

Problem

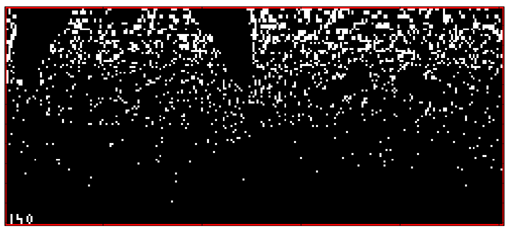
The noise repartition is not uniform.

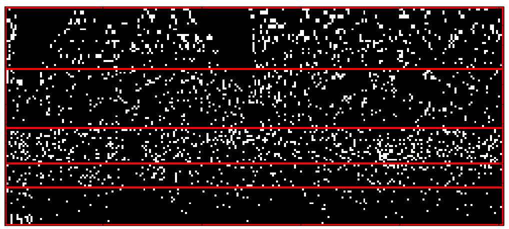




Solution

Splitting the image and treat each subimage separately.





Simulation

Simulation

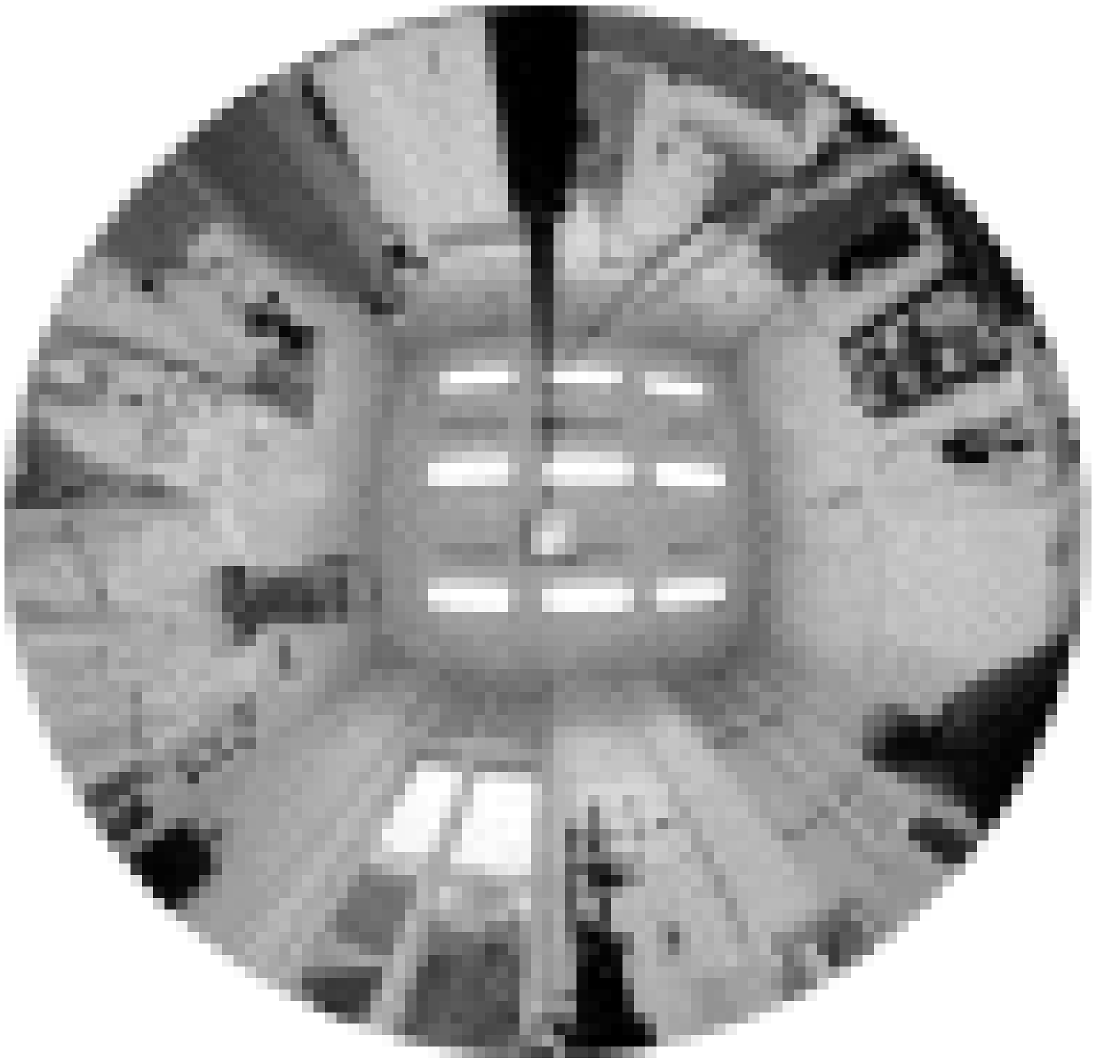
Conclusion

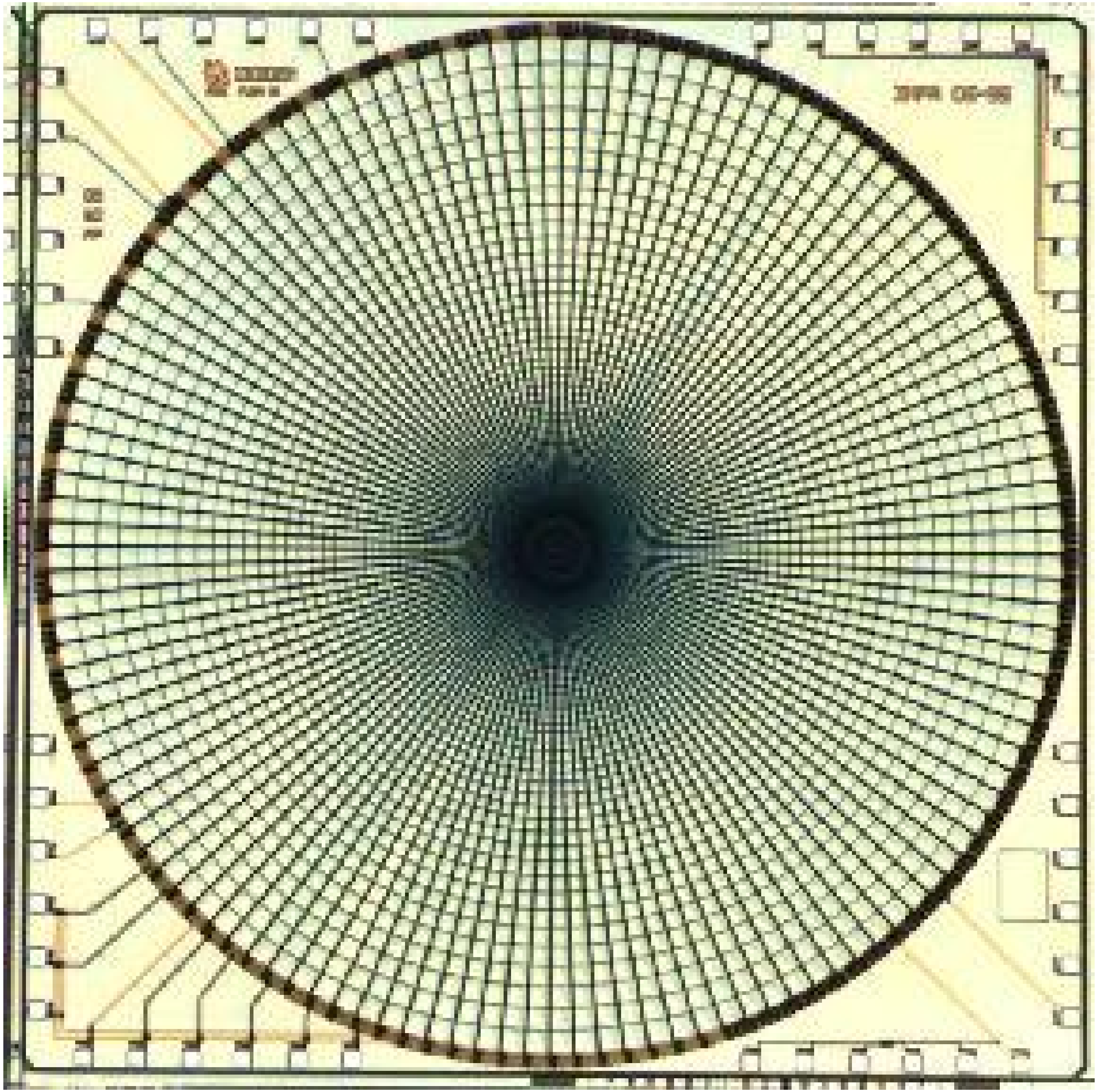
- The designed mirror shape corresponds to the requirements.
- It is possible to derive shapes in order to control the image resolution.
- The simulation shows that motion detection is possible with images set by SVAVISCA resolution.

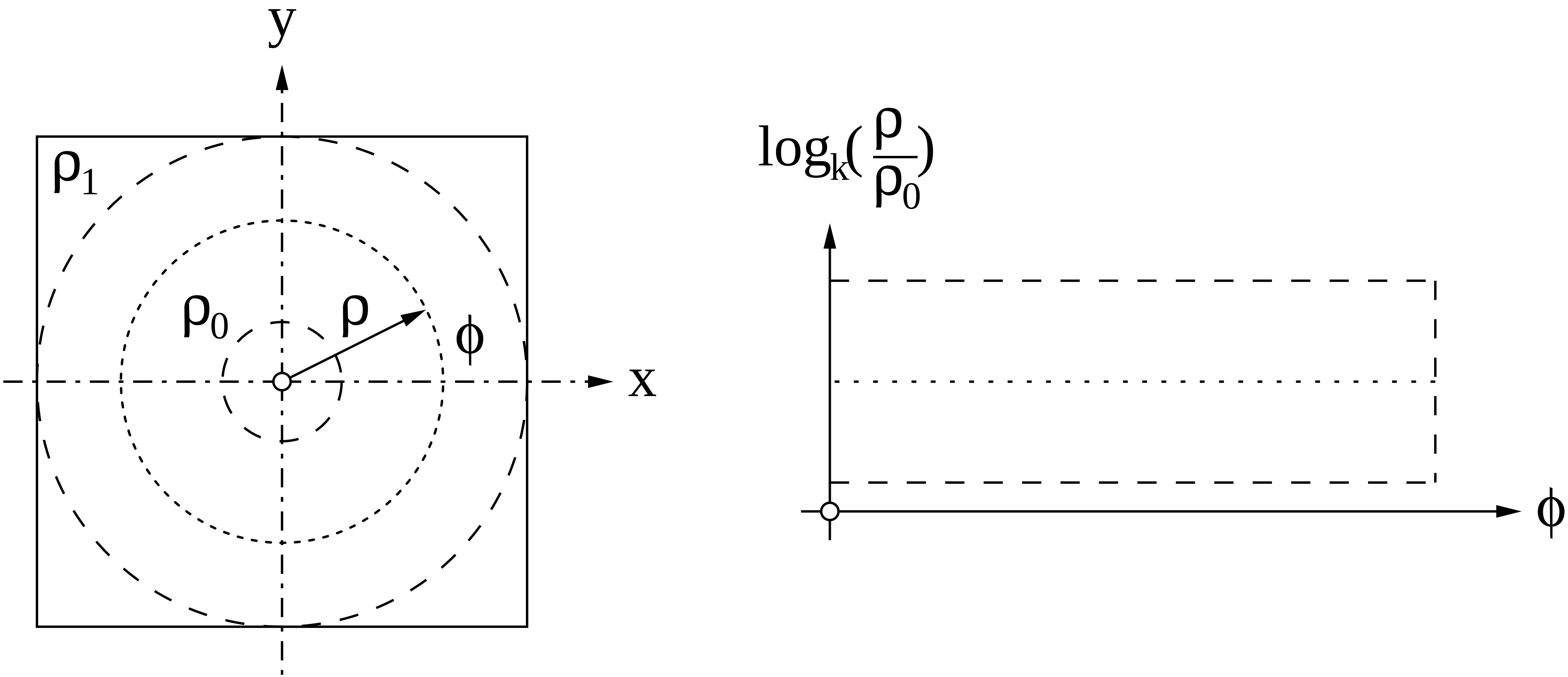
Outlook

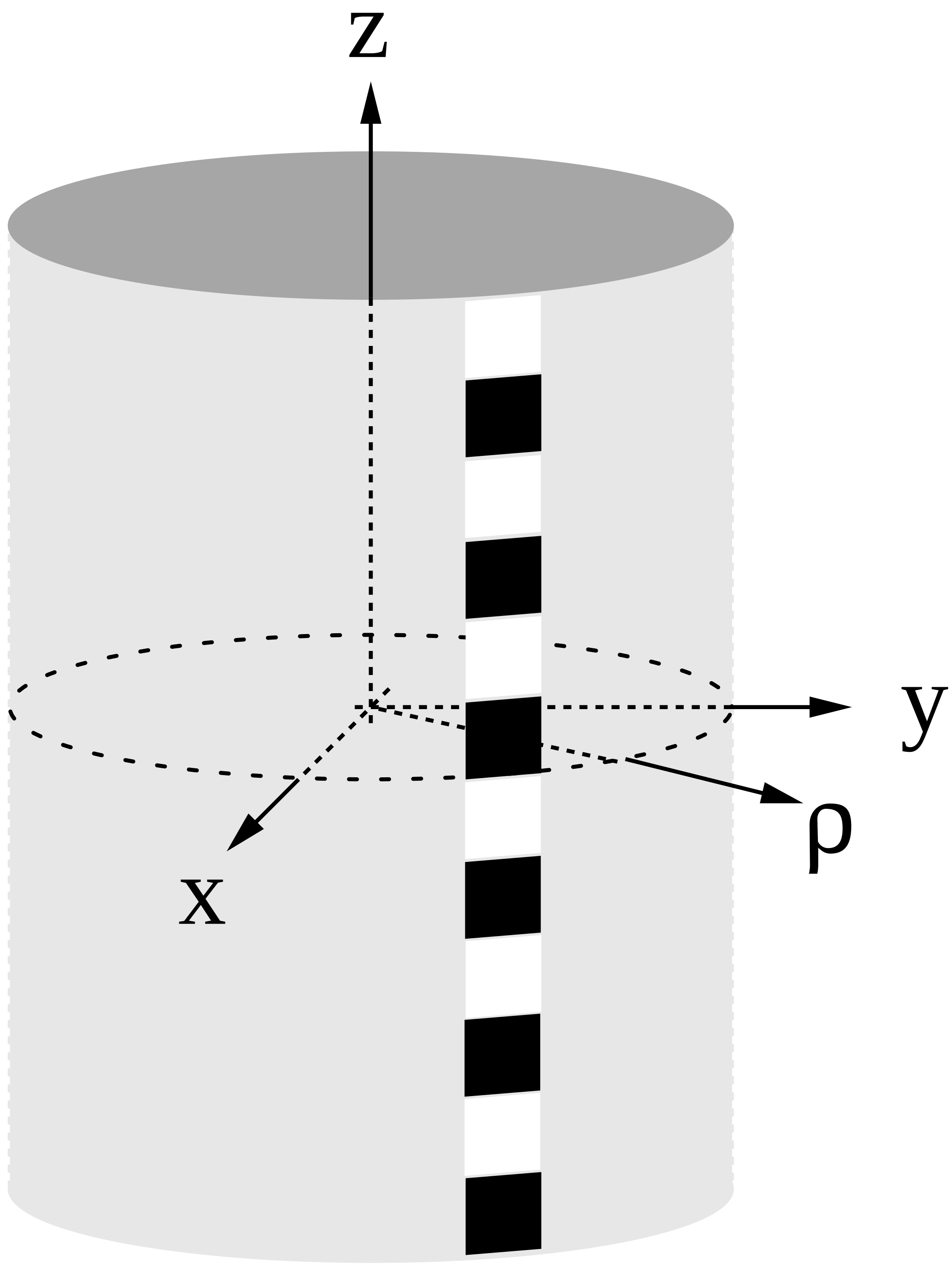
- Examine the omnidirectional camera with the new shape and the SVAVISCA imager.
- Examine the motion detection algorithm with the new omnidirectional camera.
- Elaborate applications.


PULNIX
PROGRESSIVE SCAN

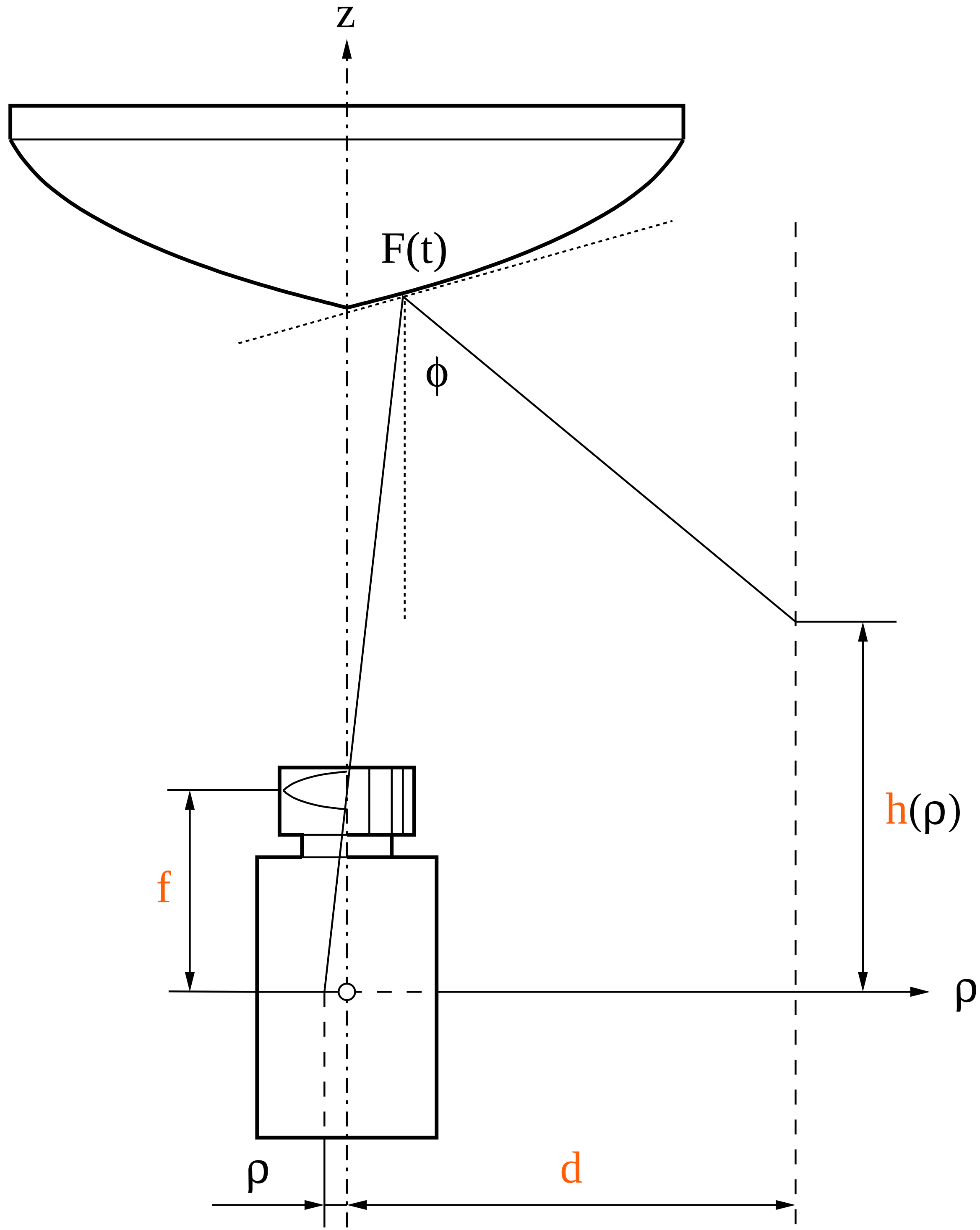




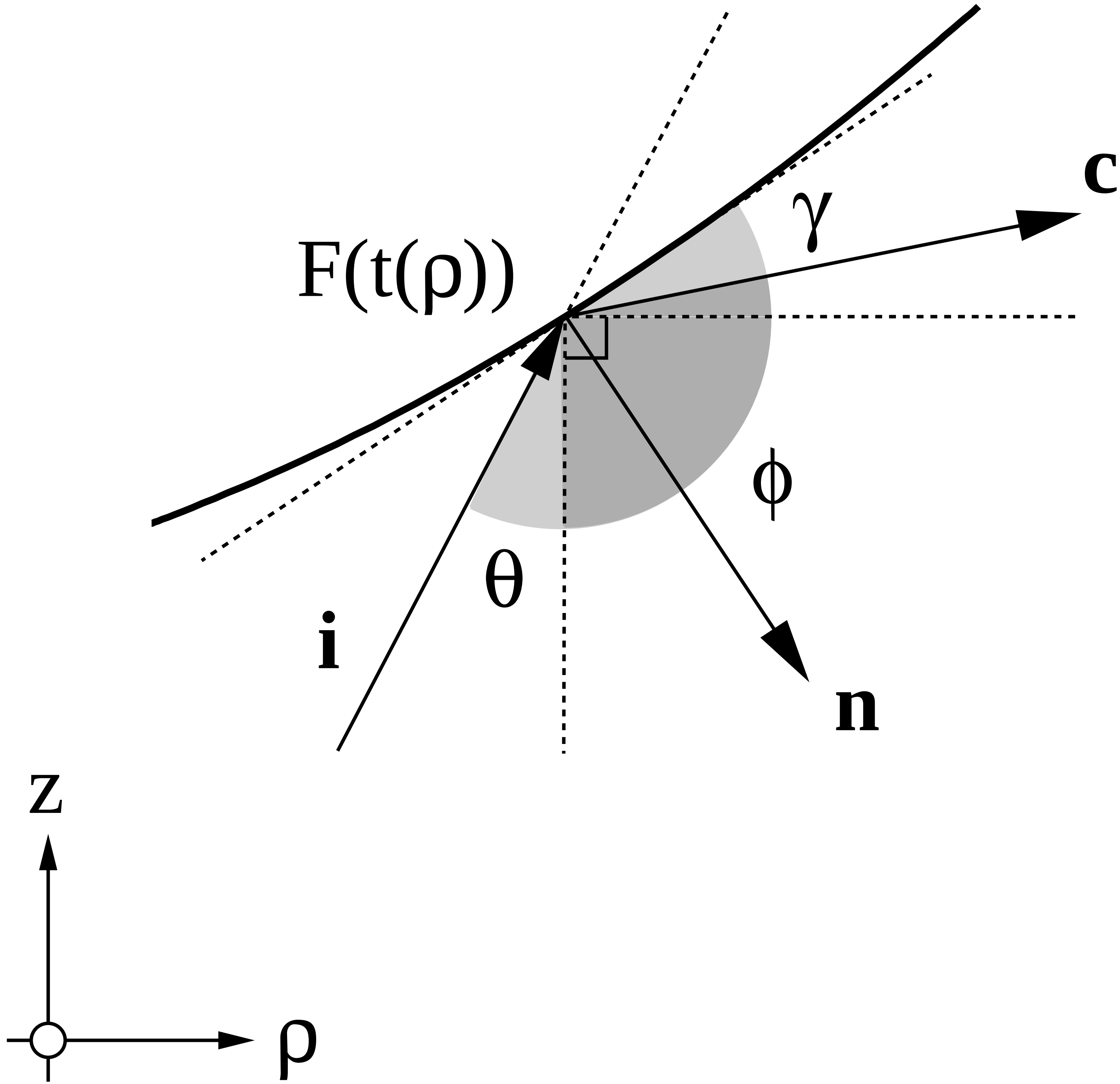

y
x
ρ_1
ρ_0
ρ
ϕ
$\log_k(\frac{\rho}{\rho_0})$
ϕ



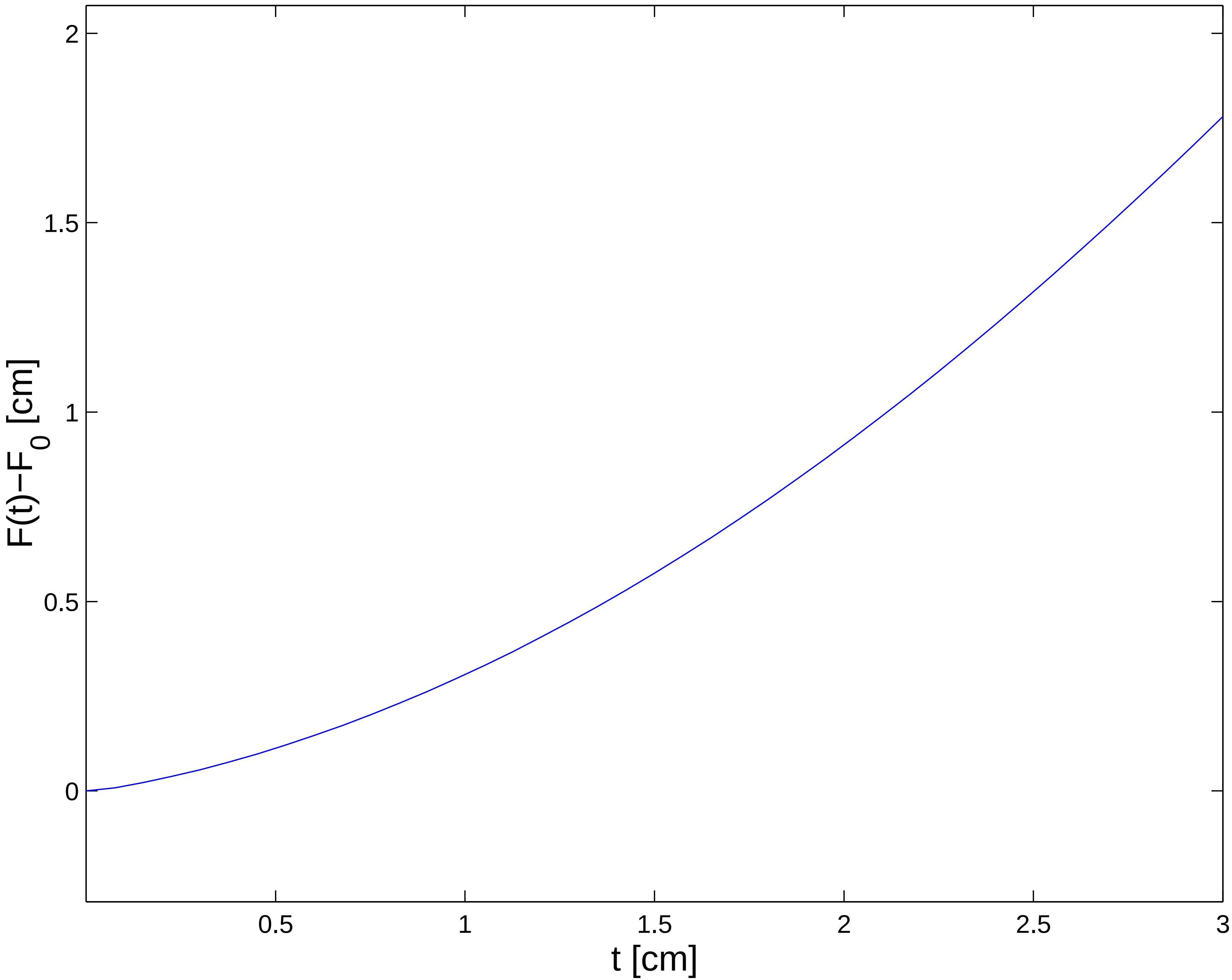
z
y
ρ
x



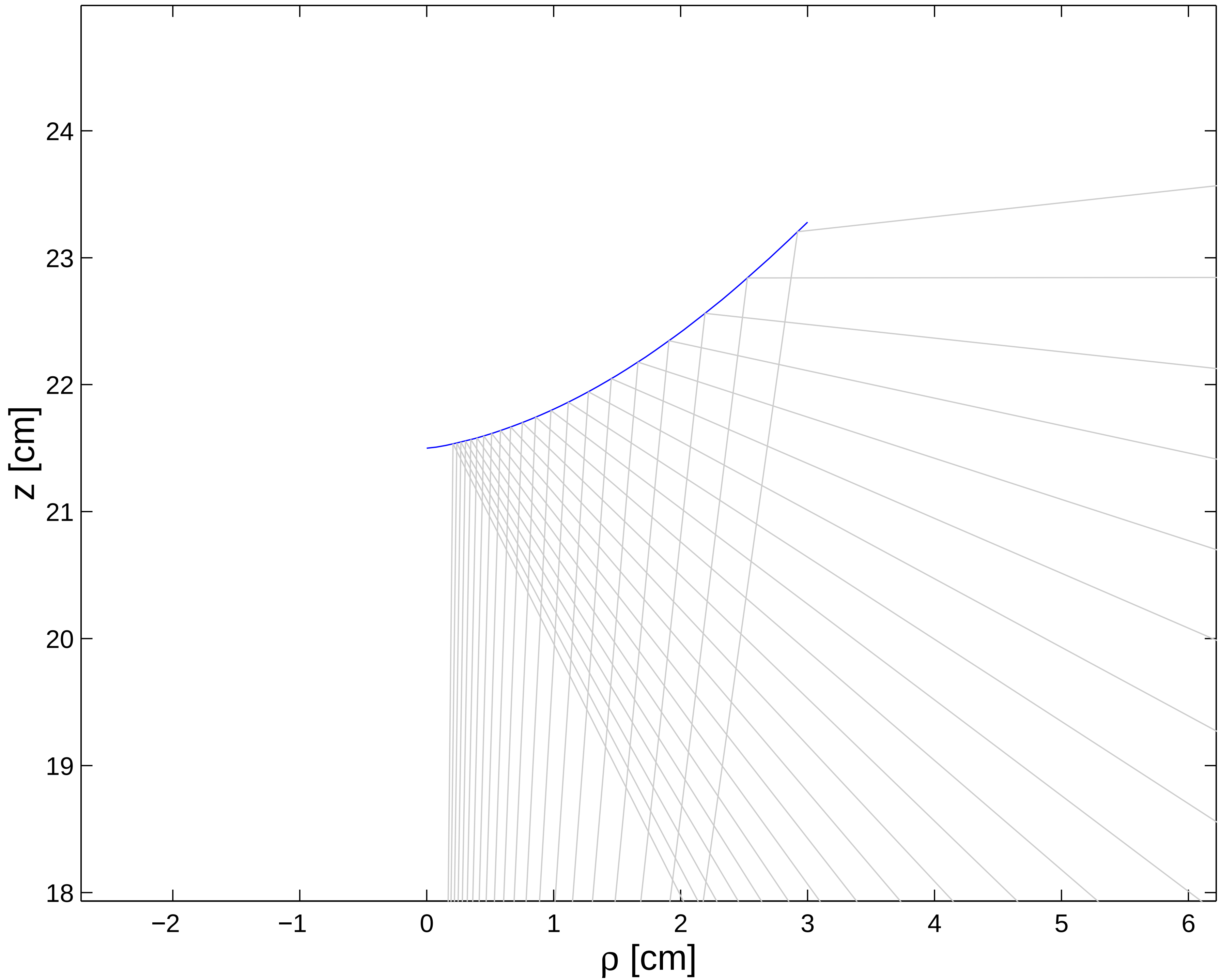
z
F(t)
ϕ
h(ρ)
f
ρ
ρ
d

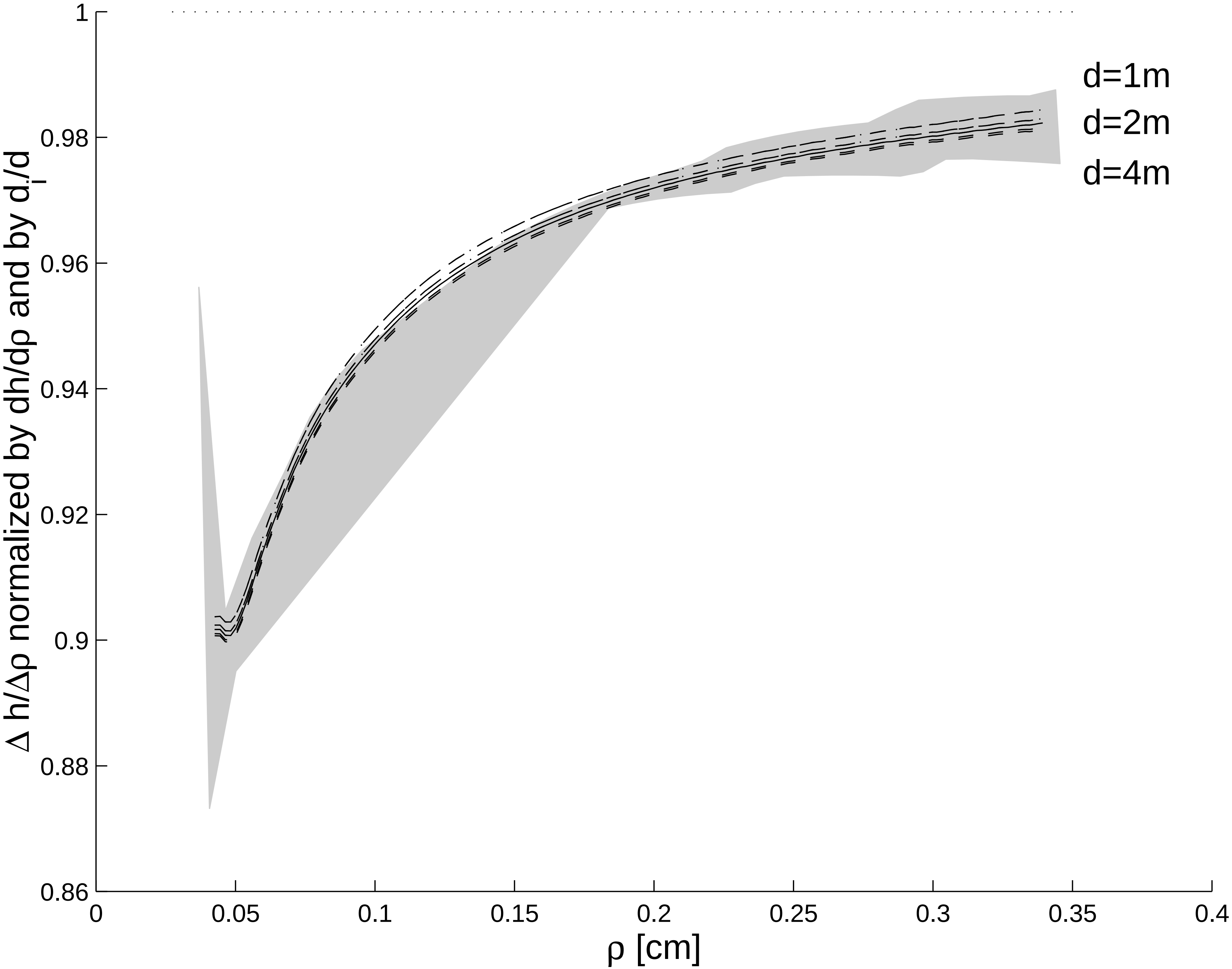


F(t(ρ))
c
γ
ϕ
θ
i
n
z
ρ

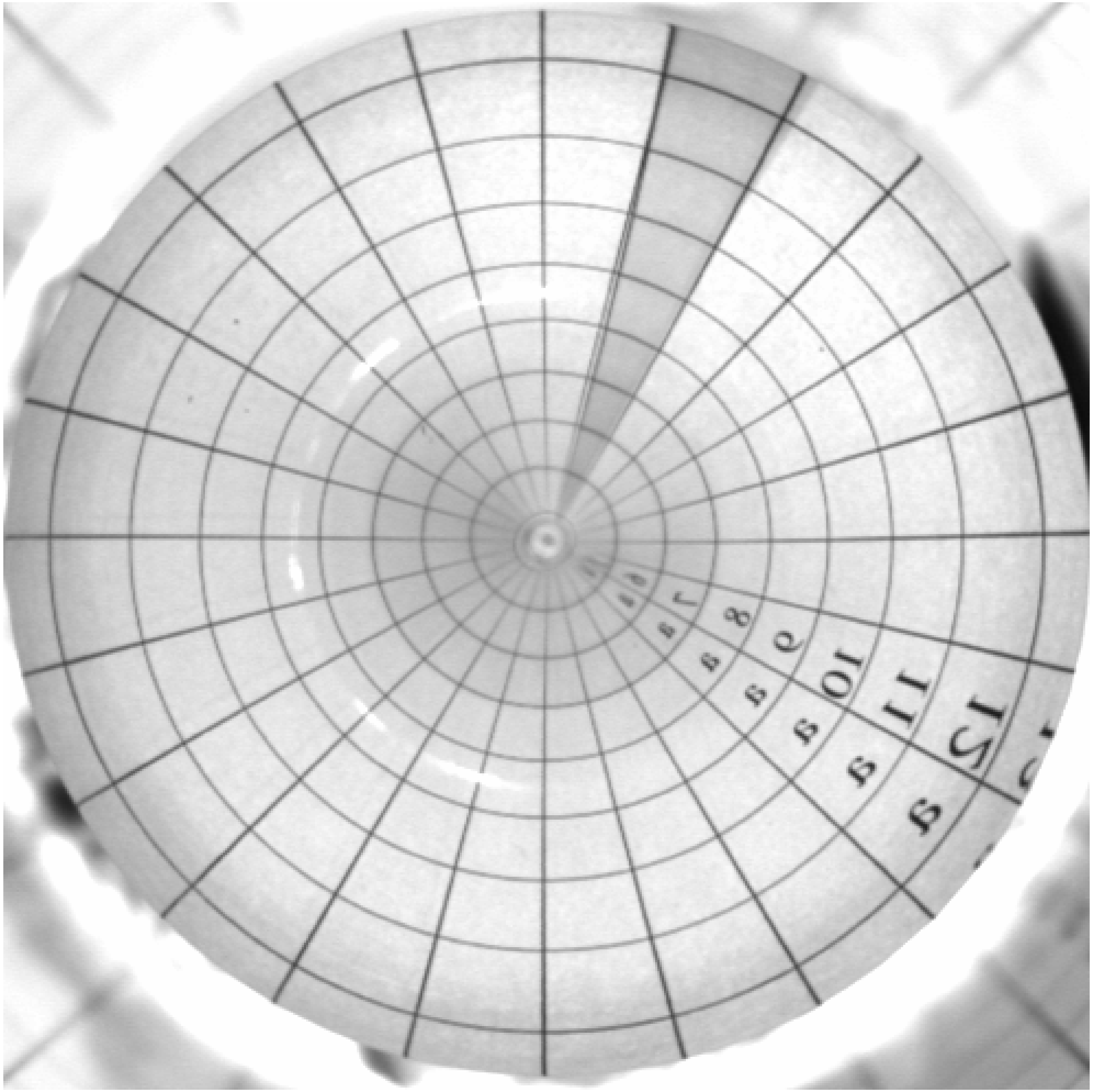


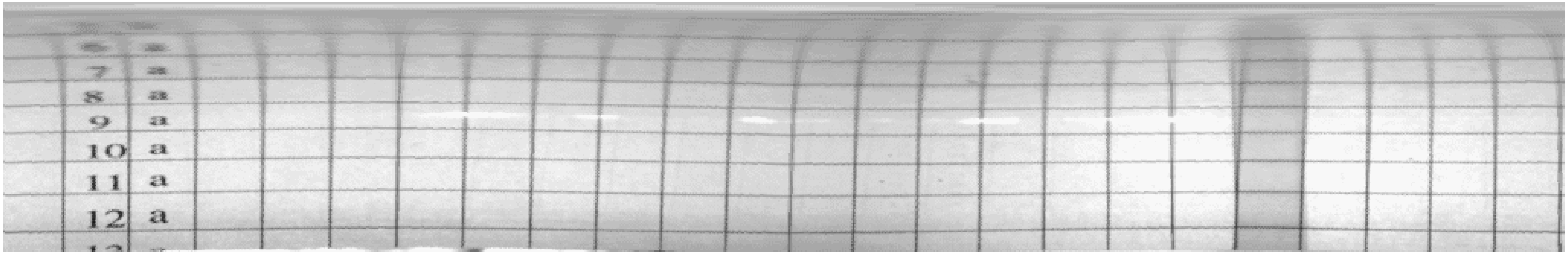
F(t)−F0 [cm]
t [cm]
2
1.5
1
0.5
0
0.5
1
1.5
2
2.5
3


24
23
22
21
20
19
18
z [cm]
−2
−1
0
1
2
3
4
5
6
ρ [cm]

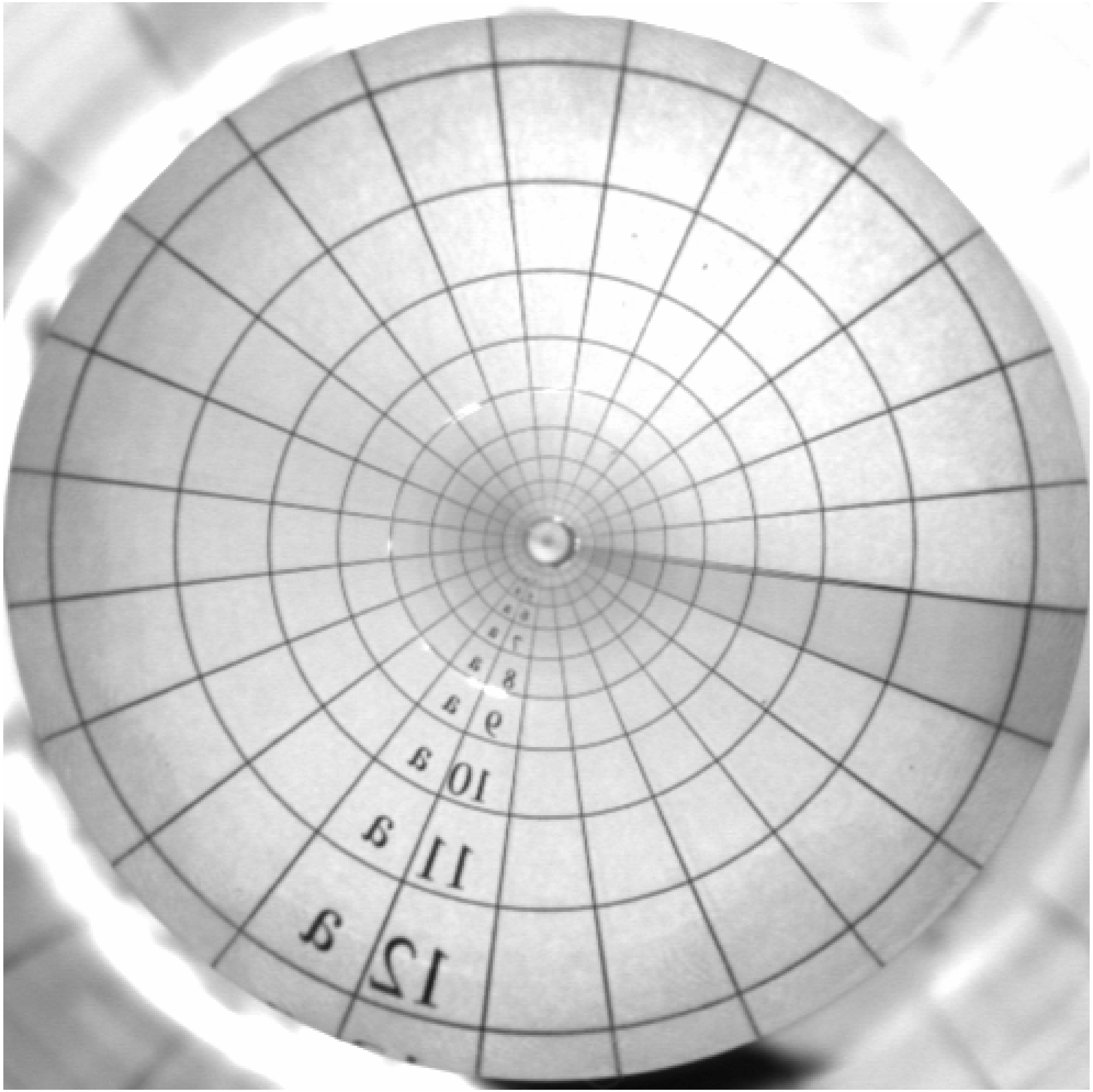


d=1m
d=2m
d=4m
Δ h/Δρ normalized by dh/dρ and by d_i/d
ρ [cm]
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4





7 a
8 a
9 a
10 a
11 a
12 a



5	a
6	a
7	a
8	a
9	a
10	a
11	a
12	a

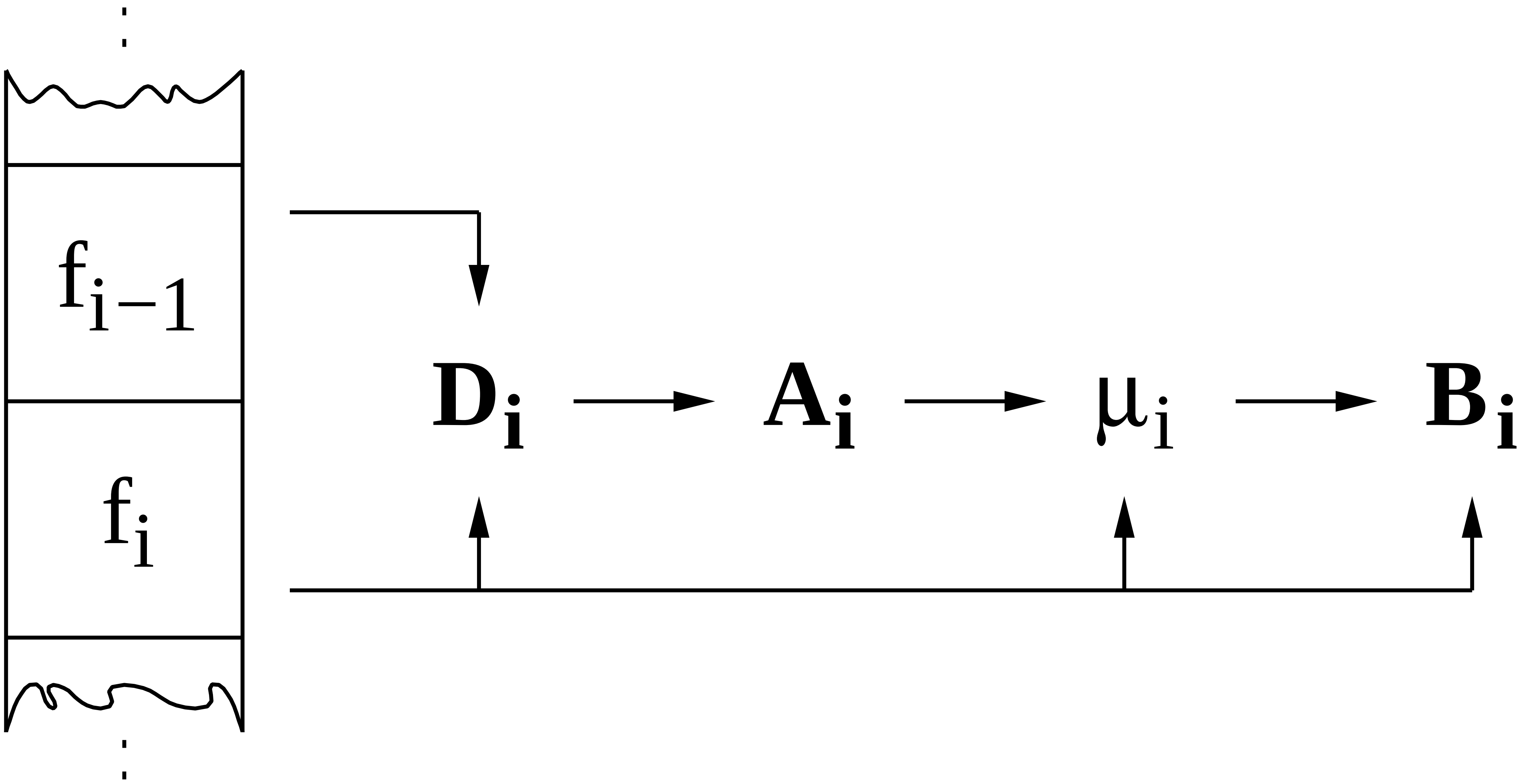

192


193

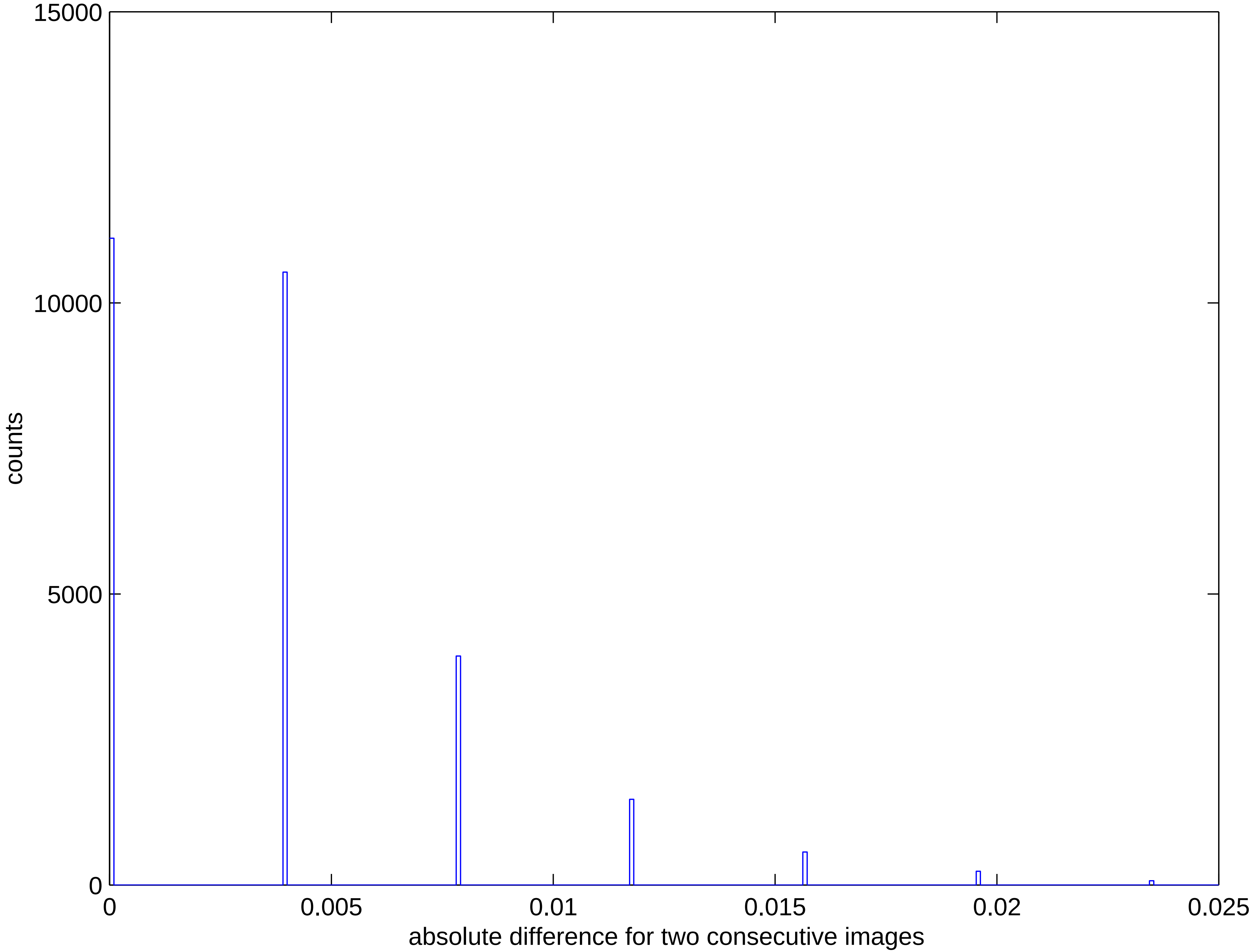

193

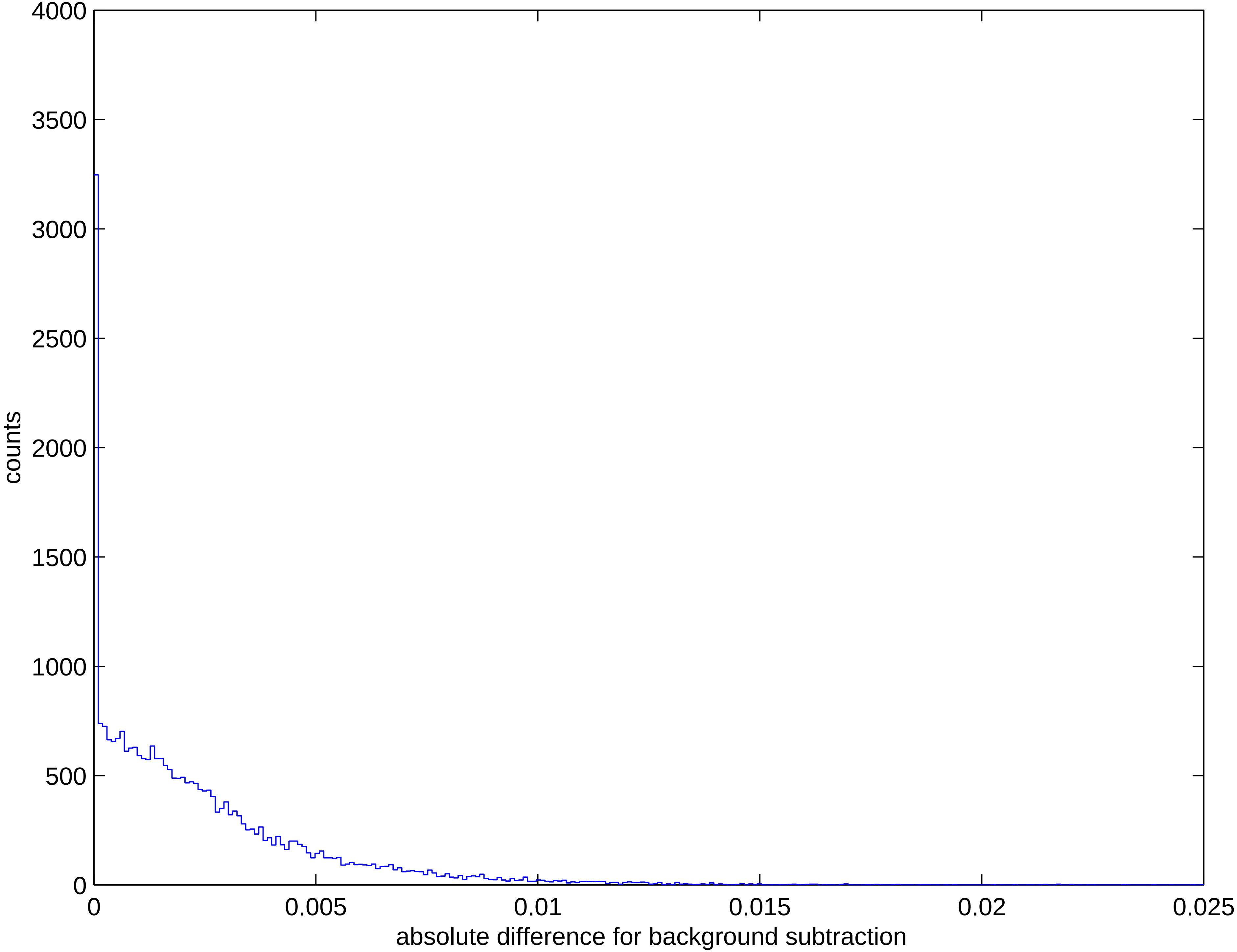

193


193

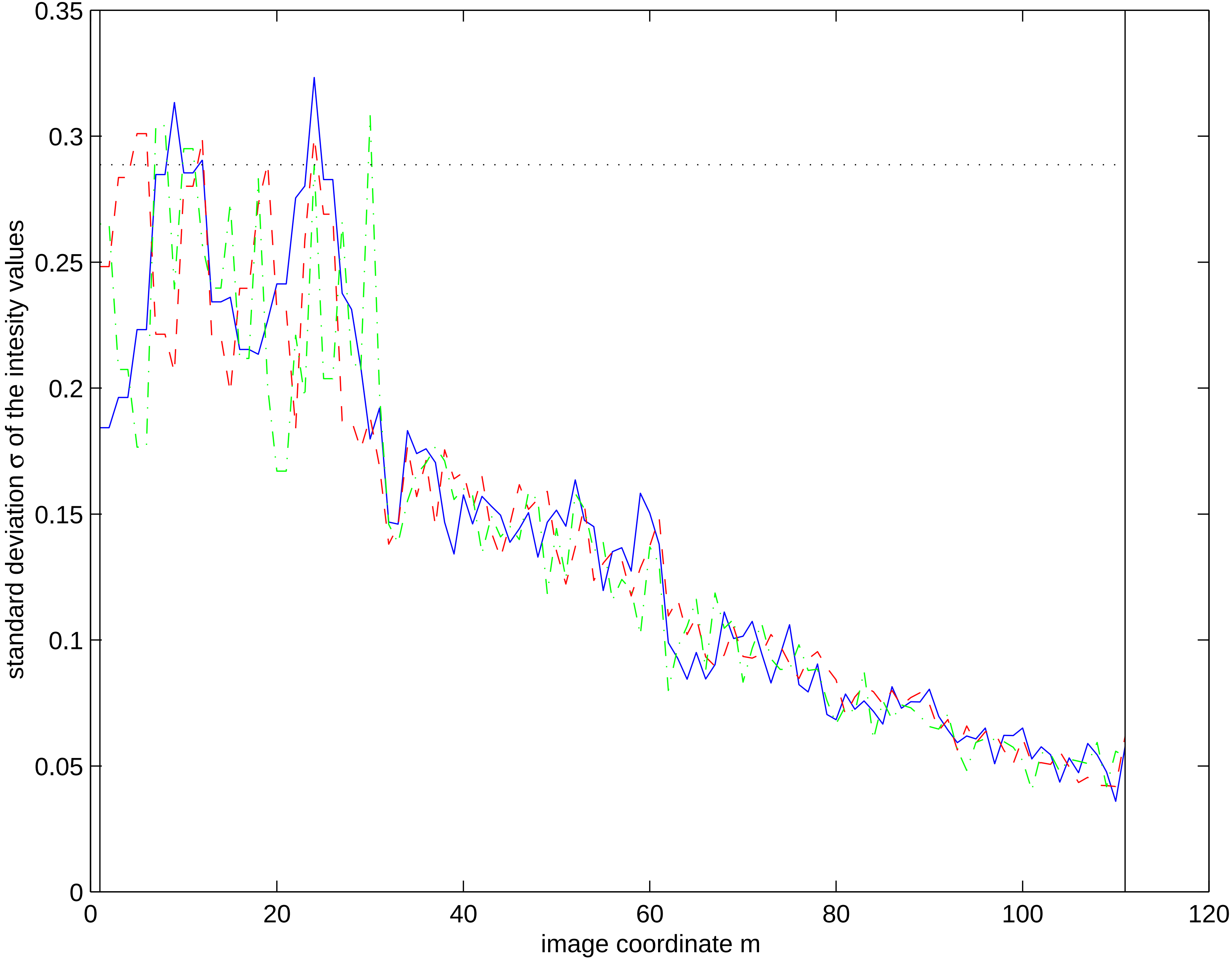


f_{i-1}
f_i
$\mathbf{D_i}$
$\mathbf{A_i}$
μ_i
$\mathbf{B_i}$


15000
10000
5000
0
counts
0
0.005
0.01
0.015
0.02
0.025
absolute difference for two consecutive images



4000
3500
3000
2500
2000
1500
1000
500
0
counts
0
0.005
0.01
0.015
0.02
0.025
absolute difference for background subtraction



0.35
0.3
0.25
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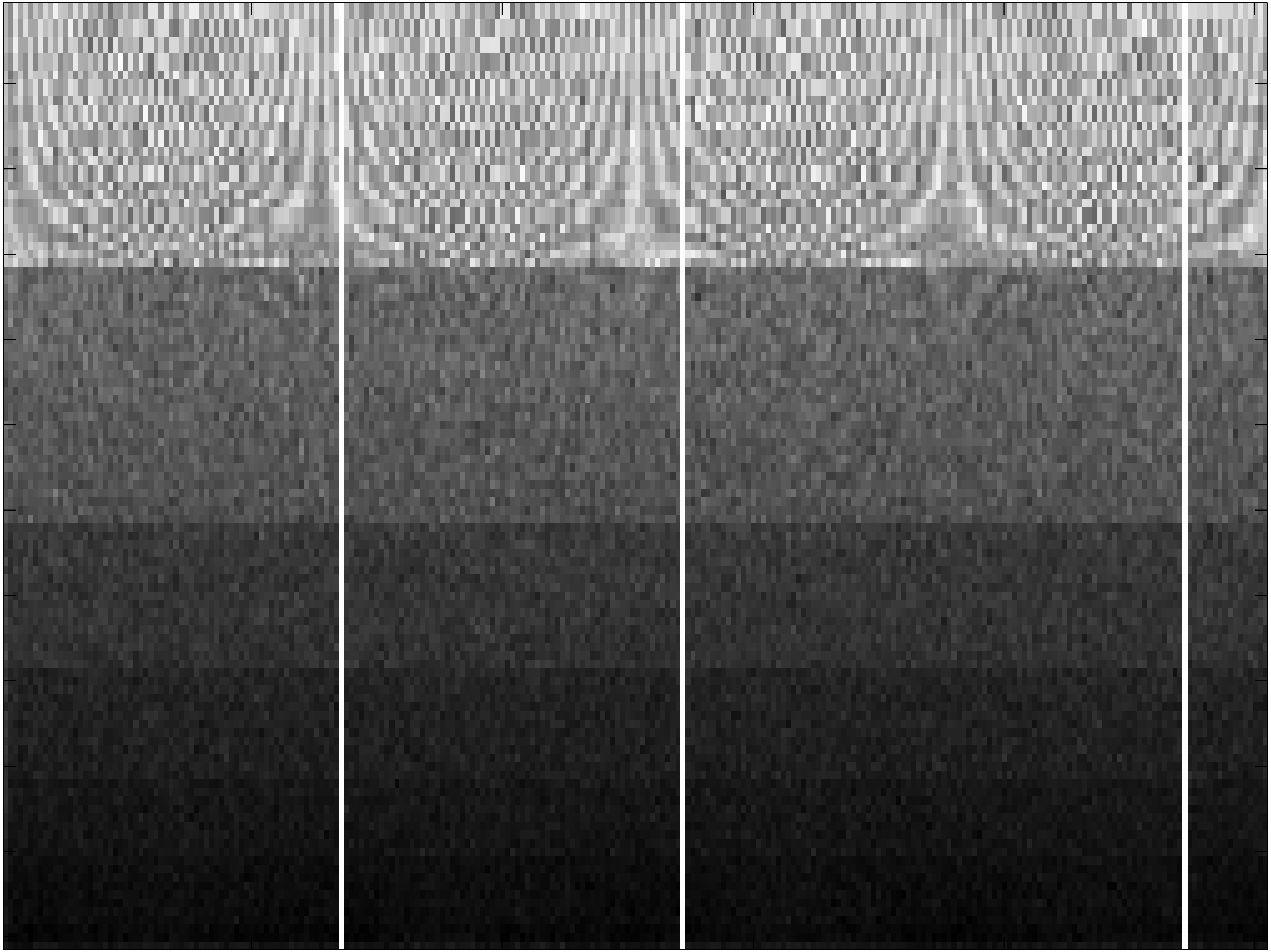
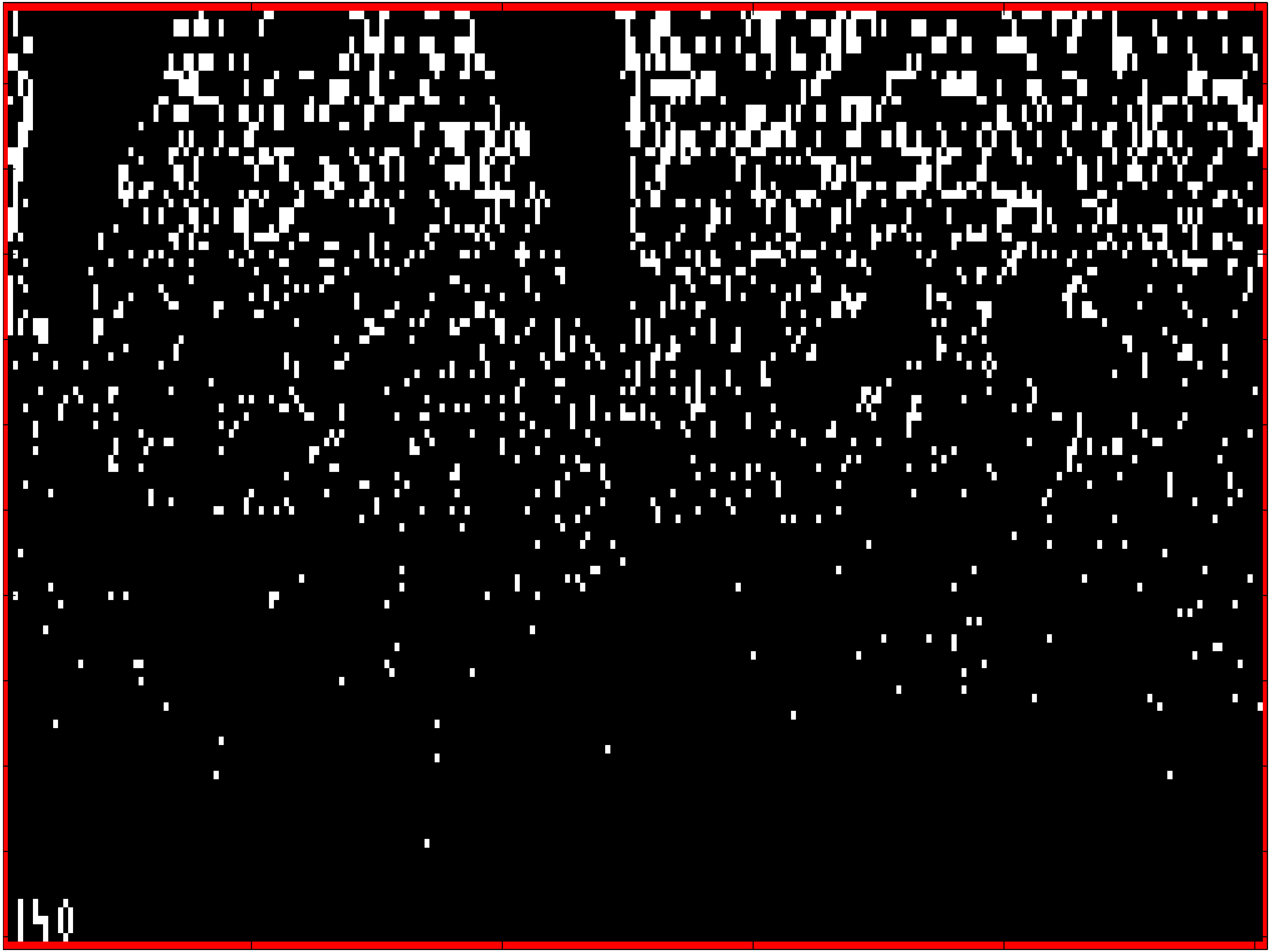
100
120
standard deviation σ of the intesity values
image coordinate m




150