

ZAVRŠNI RAD br. 3667

Mjerenje udaljenosti u ravnini ceste kamerom postavljenom na vozilu

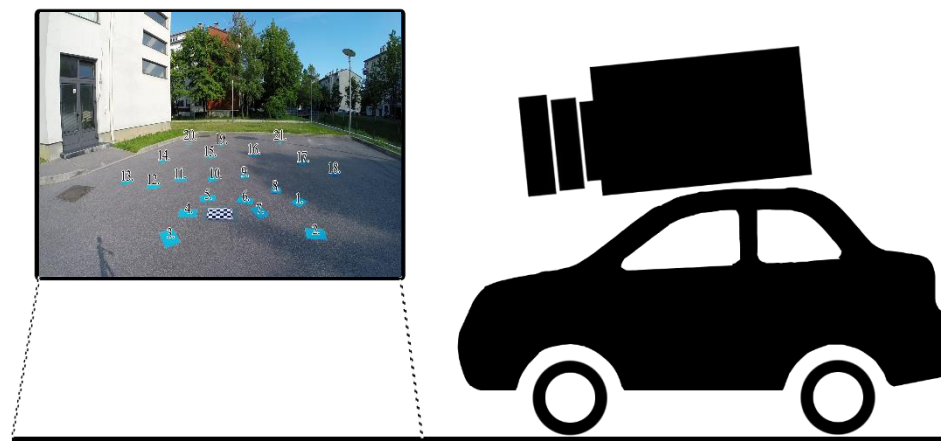
Josip Milić

Mentor: Izv. prof. dr. sc. Siniša Šegvić

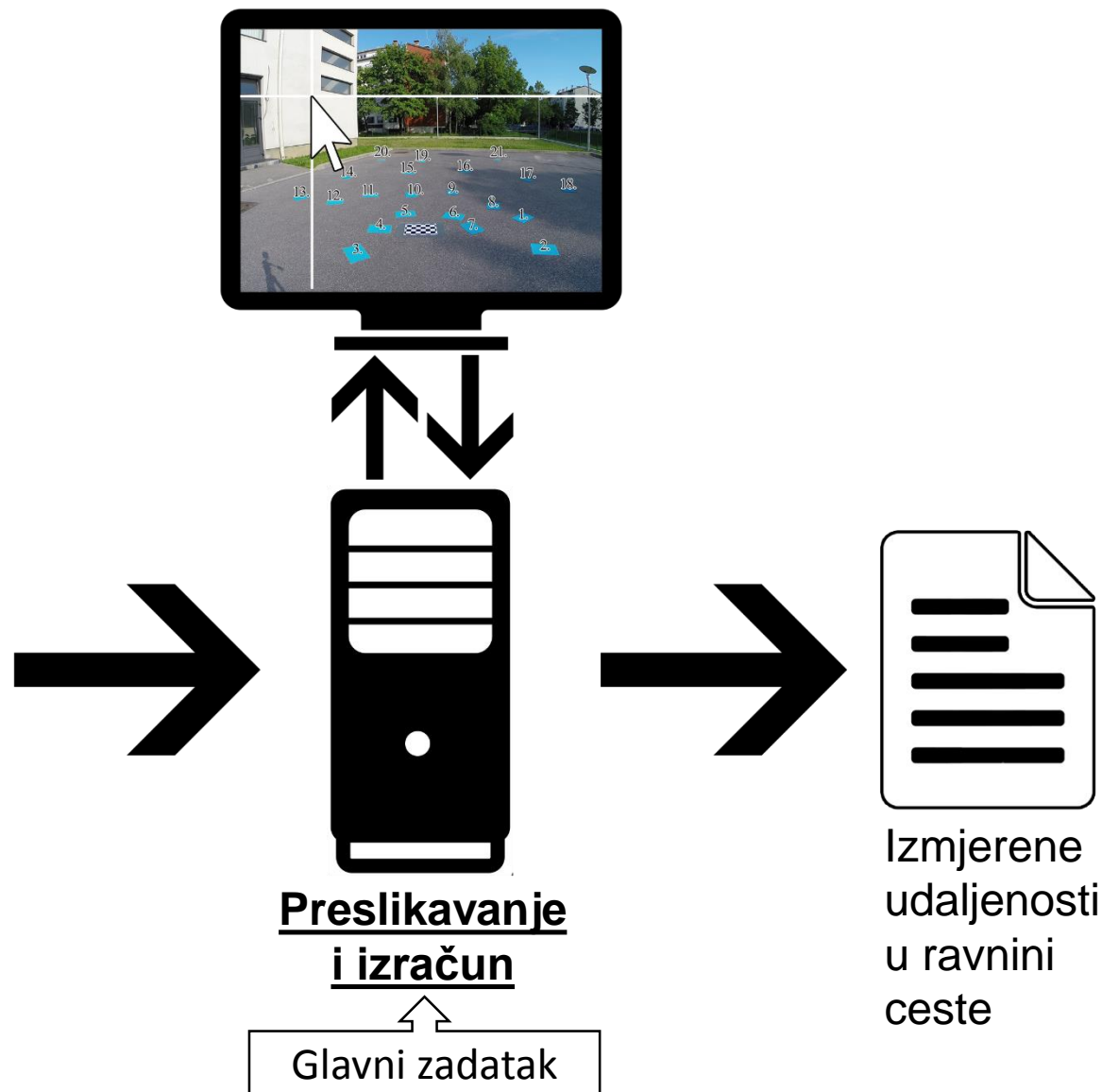
Zagreb, srpanj 2014.

Uvod

Prikaz i odabir točaka u ravnini ceste



Snimanje ceste kamerom postavljenom na vozilu



Uvod

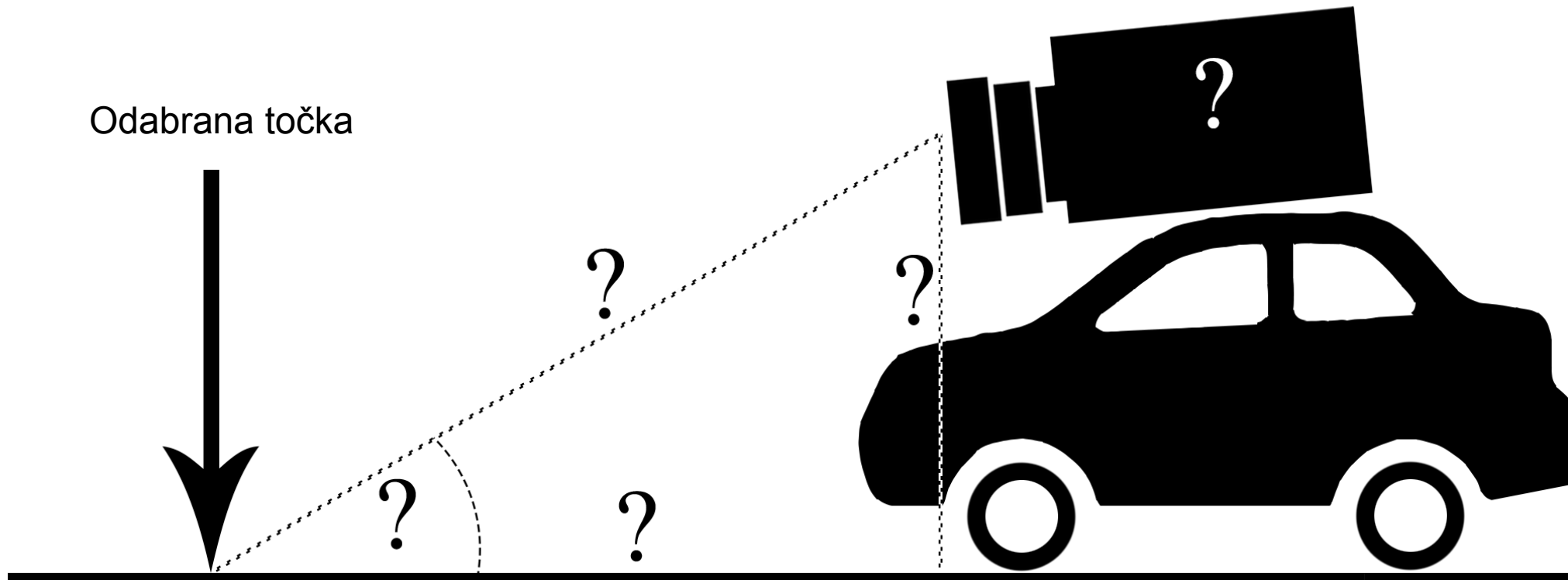
Problemi:

Nepoznata nam je visina na kojoj je kamera.

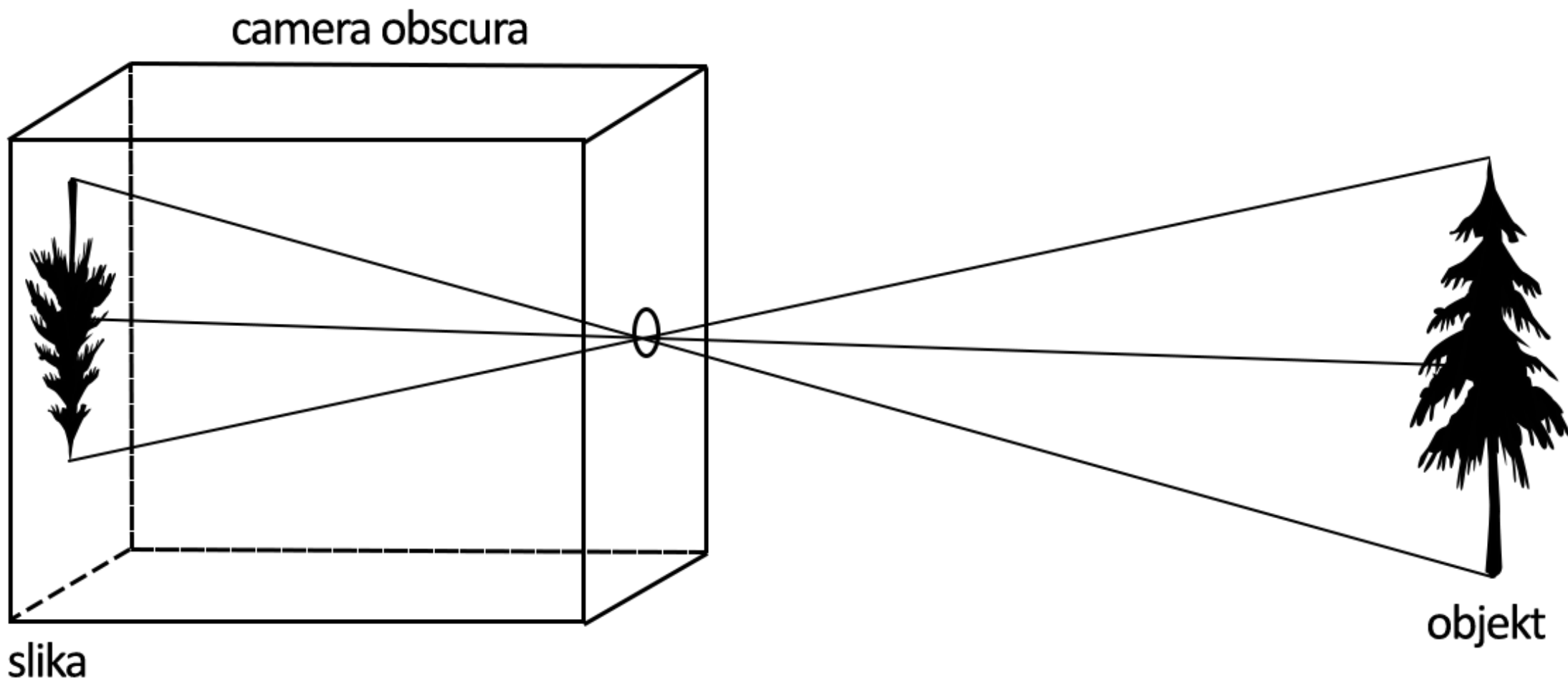
Nepoznate su nam ostale udaljenosti i kut.

Gdje se nalazi točka na slici?

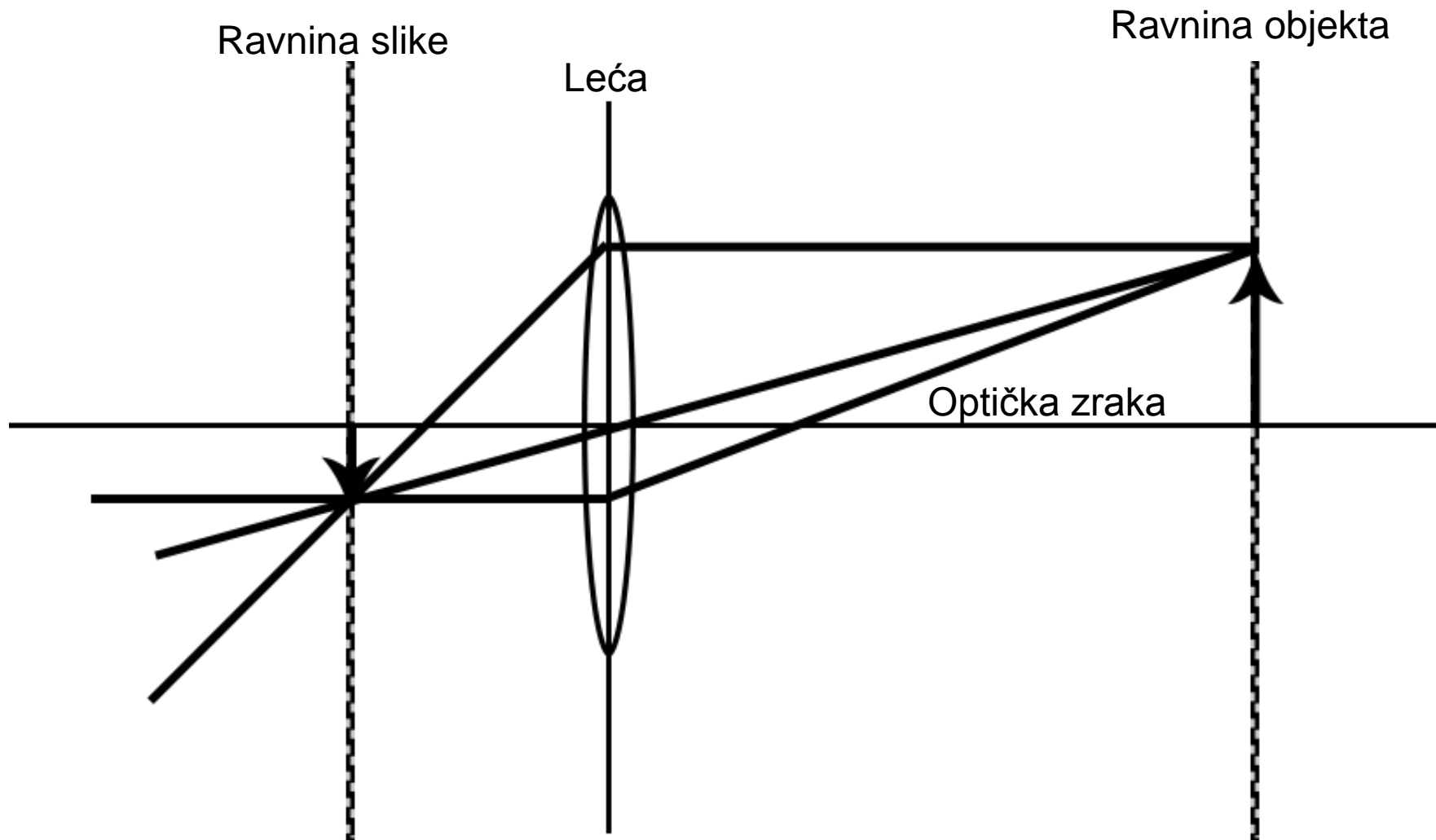
Dobiva li se isti rezultat ako se koristi druga kamera?



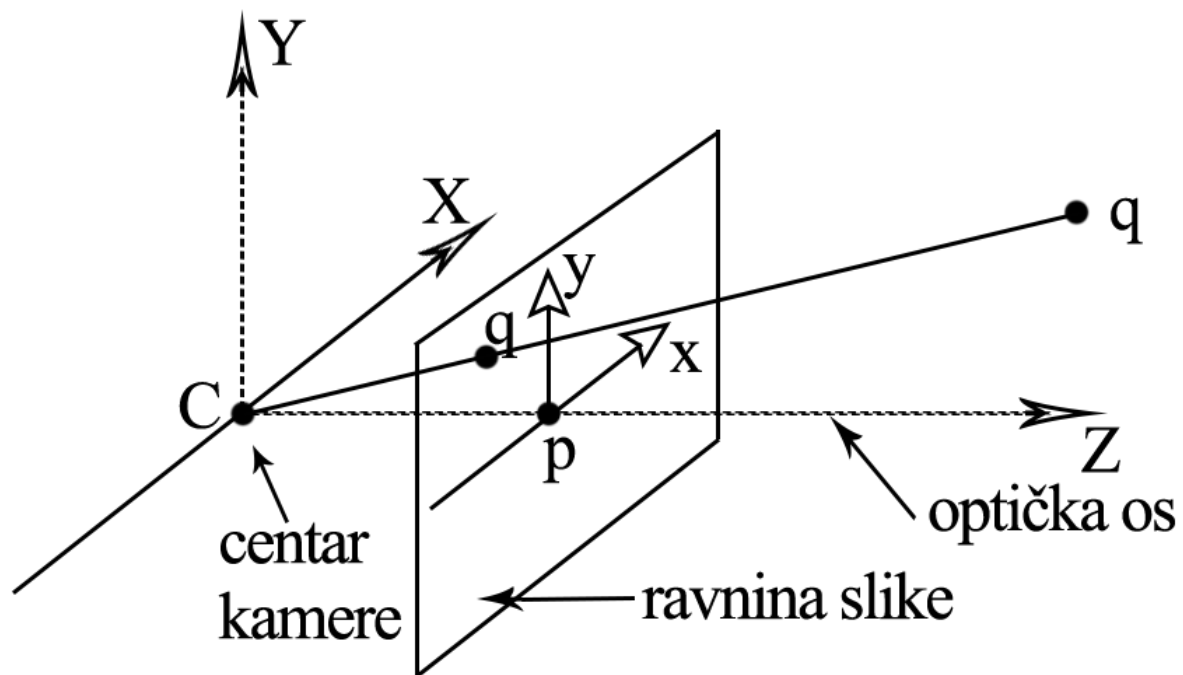
Model stvaranja slike



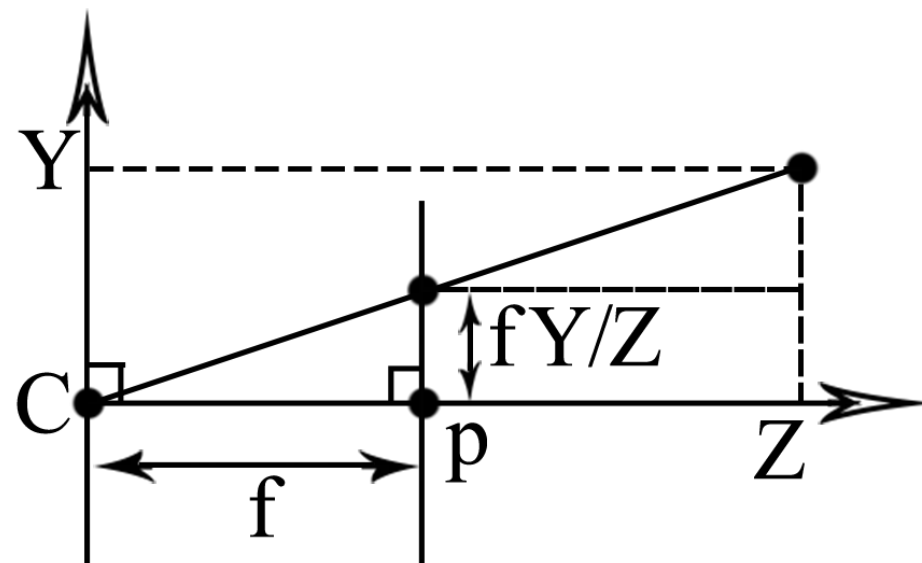
Model stvaranja slike



Model stvaranja slike



$$(X, Y, Z)^T \mapsto (fX/Z, fY/Z)^T$$



$$\begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \mapsto \begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

Model stvaranja slike

$$(X, Y, Z)^T \mapsto (fX/Z + c_x, fY/Z + c_y)^T$$

$$(c_x, c_y)^T \leftarrow \boxed{\text{Koordinata probodišta p ravnine slike}}$$

$$\begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \mapsto \begin{pmatrix} fX + Zc_x \\ fY + Zc_y \\ Z \end{pmatrix} = \begin{bmatrix} f & 0 & c_x & 0 \\ 0 & f & c_y & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

$$\boxed{\text{Točka slike}} \Rightarrow q = K[I \mid 0] Q_{cam}$$

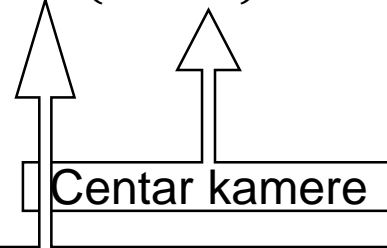
$$\boxed{\text{Točka prostora}} \uparrow$$

$$K = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \leftarrow \boxed{\text{Matrica kamere}}$$

Model stvaranja slike

$$\tilde{Q}_{cam} = R (\tilde{Q} - \tilde{C})$$

$\tilde{x} \leftarrow$ Nehomogen vektor točke prostora



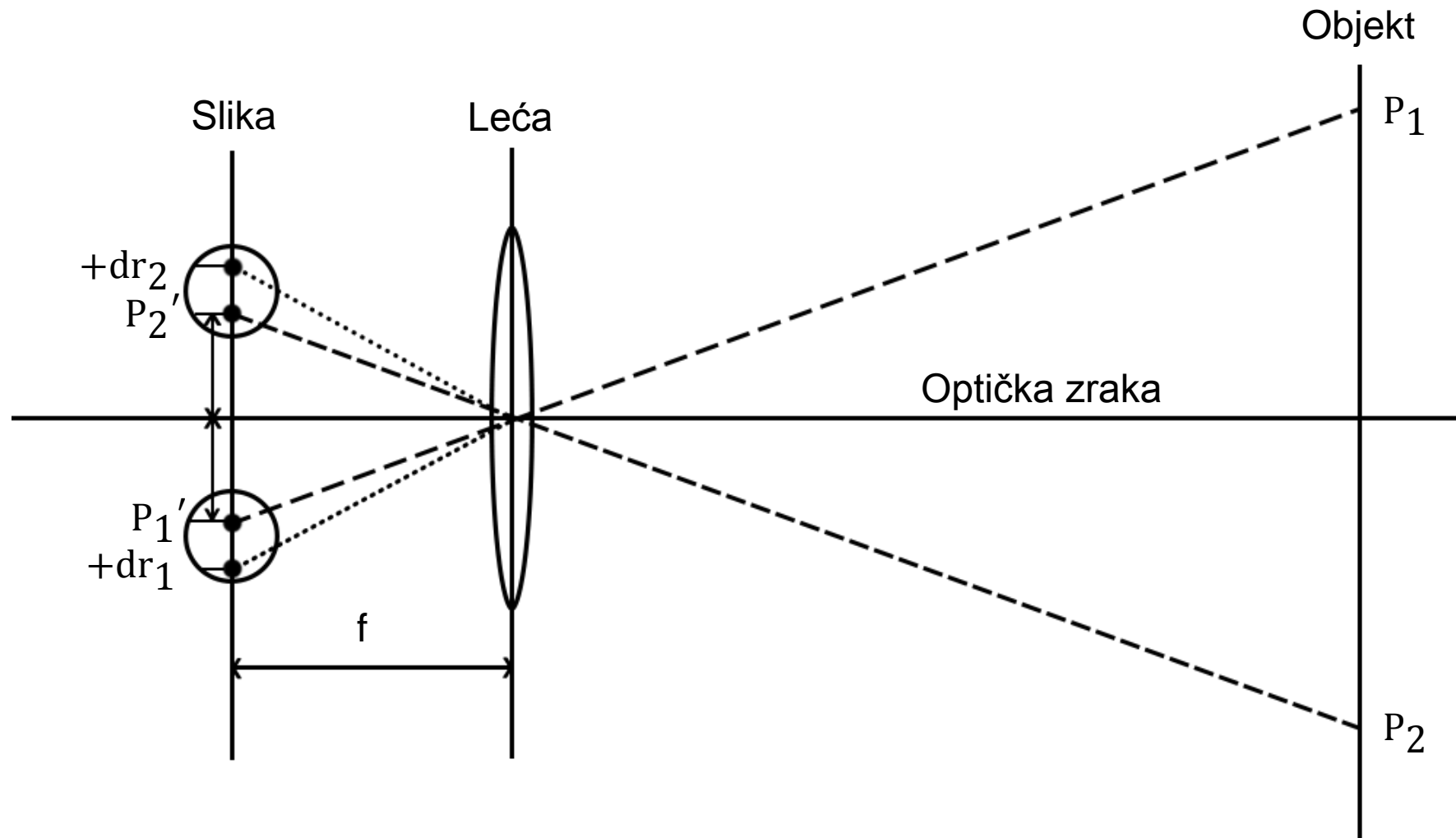
Orijentacija podsustava kamere

$$Q_{cam} = \begin{bmatrix} R & -R\tilde{C} \\ 0 & 1 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} = \begin{bmatrix} R & -R\tilde{C} \\ 0 & 1 \end{bmatrix} Q$$

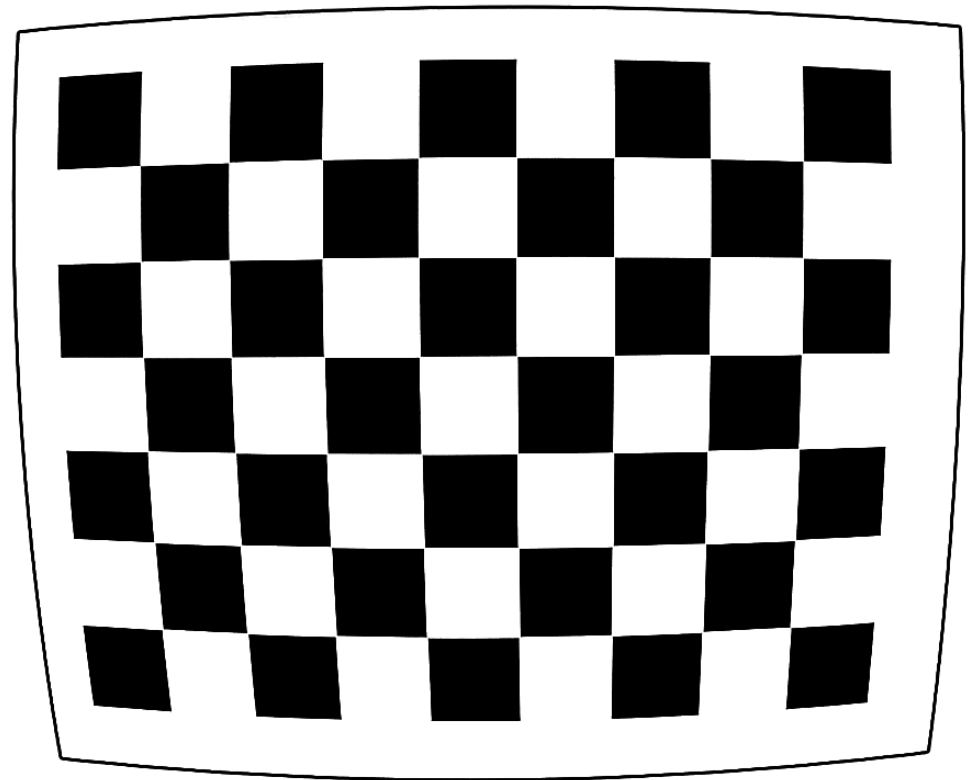
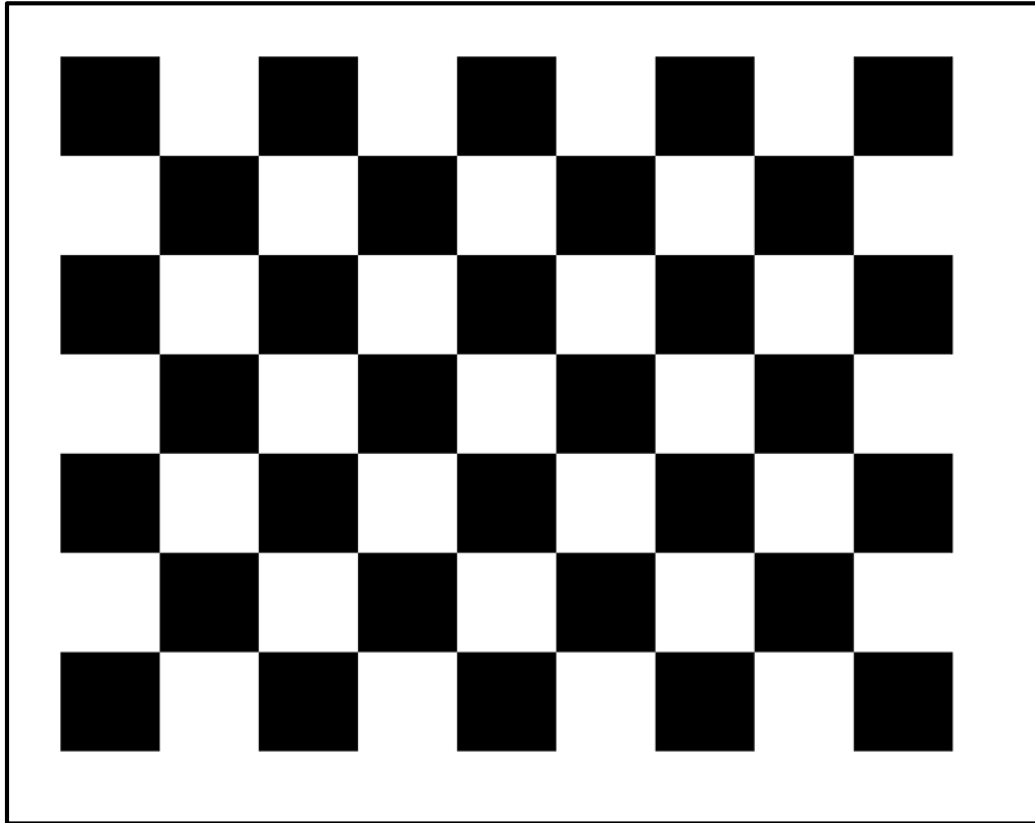
$$q = KR [I \mid -\tilde{C}] Q$$

Model stvaranja slike $\Rightarrow P = KR [I \mid -\tilde{C}]$

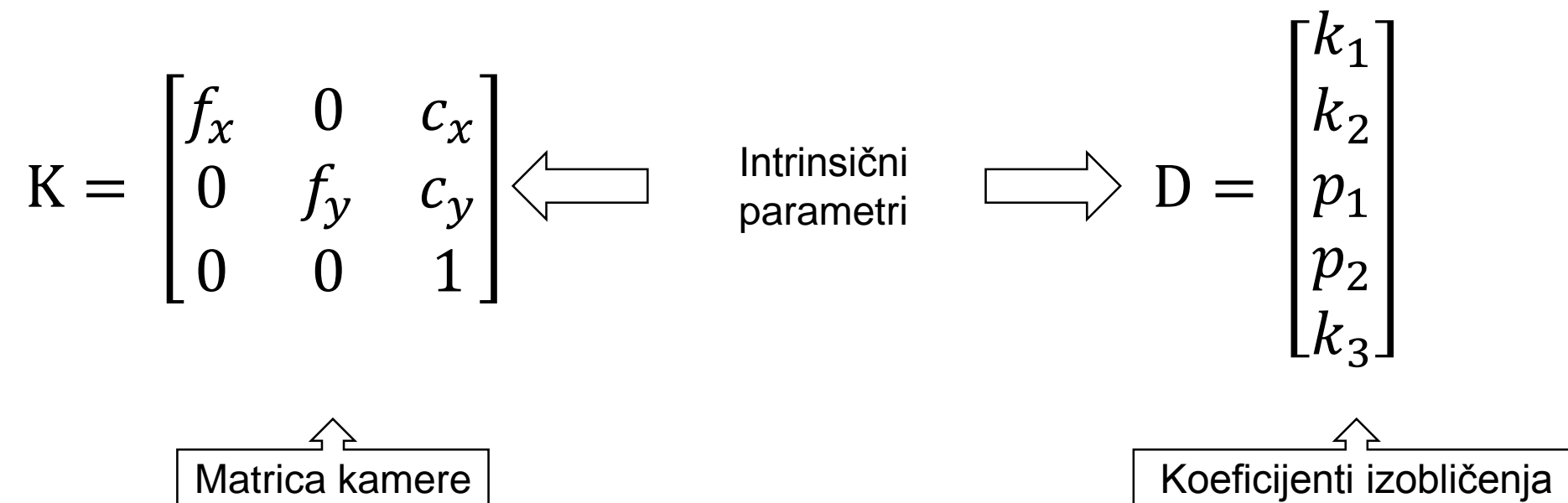
Kalibracija kamere



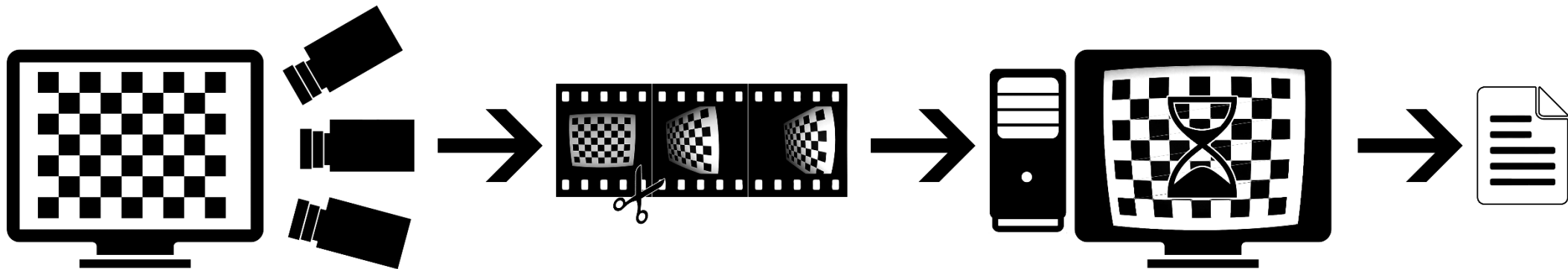
Kalibracija kamere



Kalibracija kamere



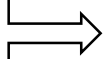
Kalibracija kamere



Kalibracija kamere

Ispravljanje radijalnog izobličenja

Ispravljena koordinata točke

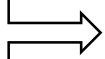


$$x_p = x \left(1 + \sum_{i=1}^n k_i r^{2i} \right)$$

$$y_p = y \left(1 + \sum_{i=1}^n k_i r^{2i} \right)$$

Ispravljanje tangencijalnog izobličenja

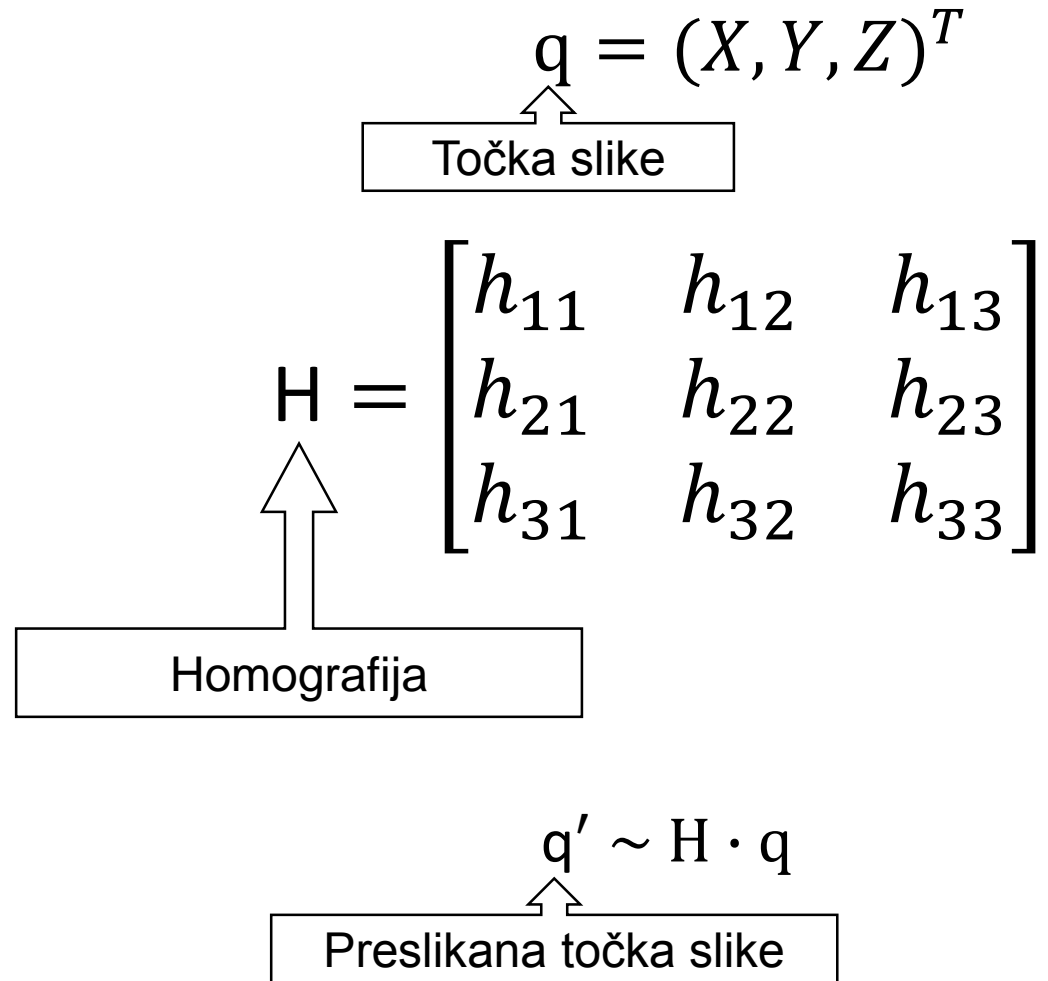
Ispravljena koordinata točke



$$x_p = x + [2p_1xy + p_2(r^2 + 2x^2)]$$

$$y_p = y + [2p_2xy + p_1(r^2 + 2y^2)]$$

Određivanje udaljenosti u ravnini ceste



Određivanje udaljenosti u ravnini ceste

$$Hx_i = \begin{bmatrix} h^1 x_i \\ h^2 x_i \\ h^3 x_i \end{bmatrix}$$

Točka slike

$$x_i' \times Hx_i = \begin{bmatrix} y_i' h^3 x_i - z_i' h^2 x_i \\ z_i' h^1 x_i - x_i' h^3 x_i \\ x_i' h^2 x_i - y_i' h^1 x_i \end{bmatrix}$$

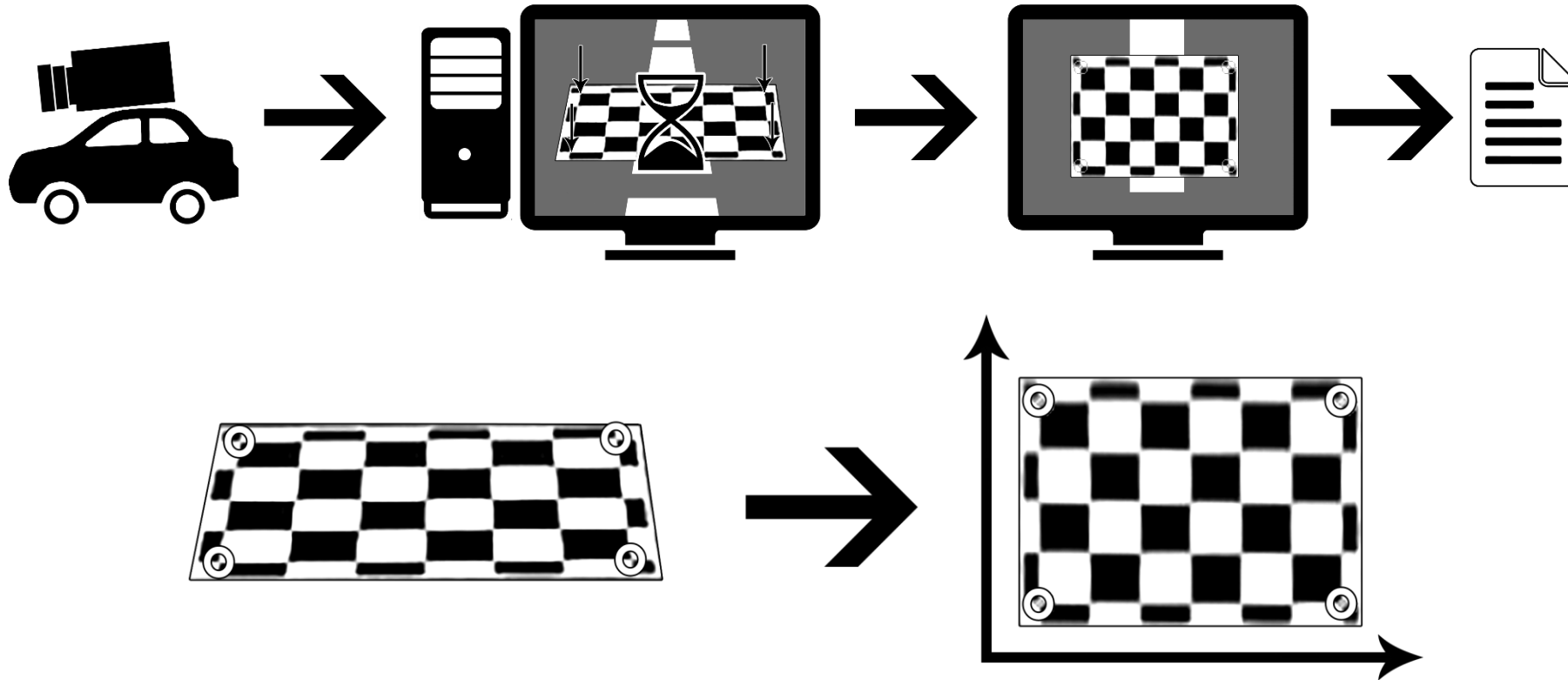
Točka slike ravnine ceste

$$\begin{bmatrix} 0^T & -z_i' x_i^T & y_i' x_i^T \\ z_i' x_i^T & 0^T & -x_i' x_i^T \\ -y_i' x_i^T & x_i' x_i^T & 0^T \end{bmatrix} \begin{bmatrix} h^1 \\ h^2 \\ h^3 \end{bmatrix} = 0$$

$$A = U \Sigma V^T$$

Metoda singularne dekompozicije

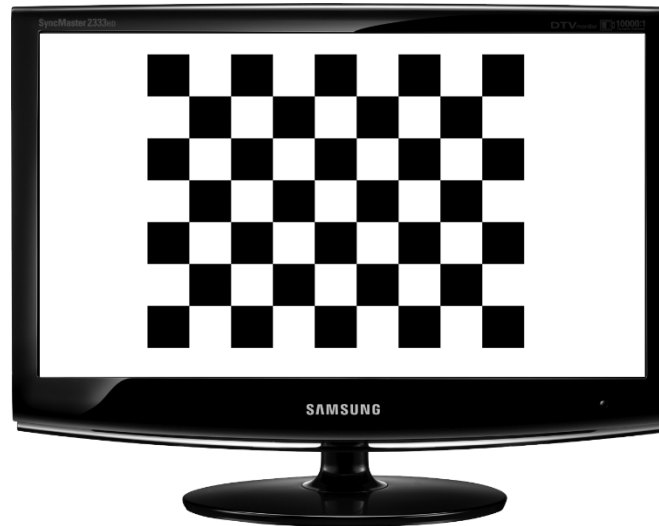
Umjeravanje matrice homografije



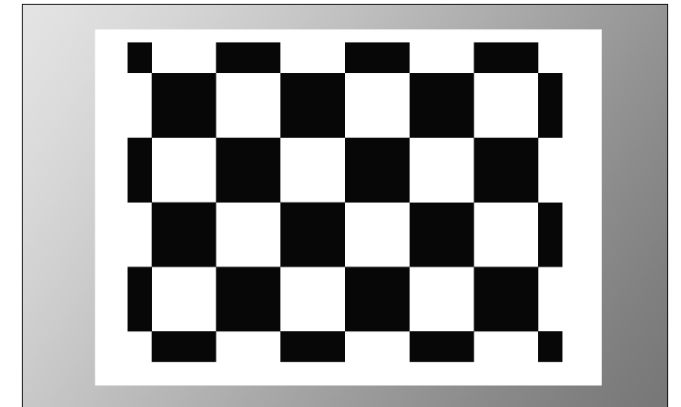
Eksperimentalni rezultati i problemi



Kamera

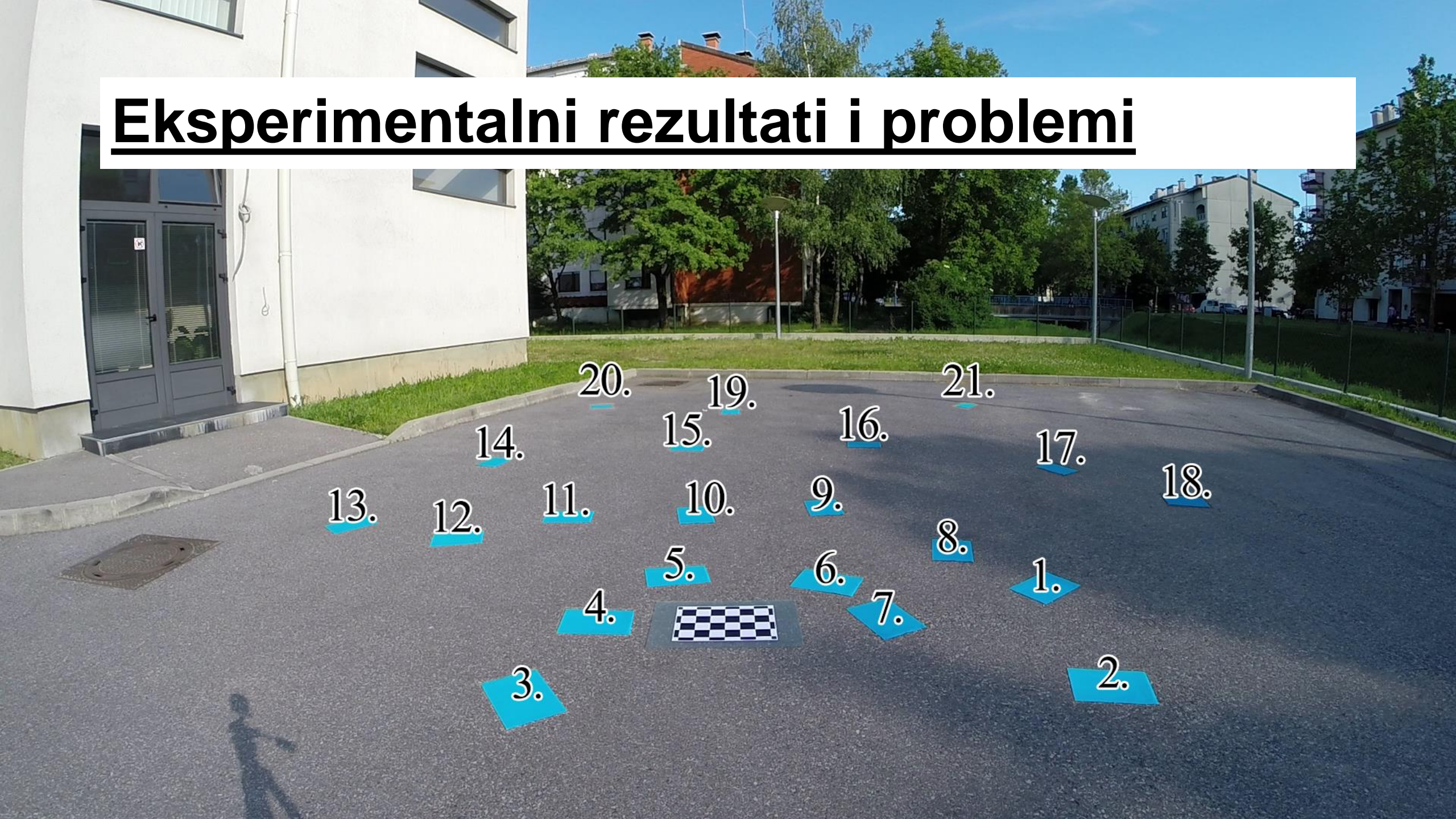


Monitor s kalibracijskim uzorkom

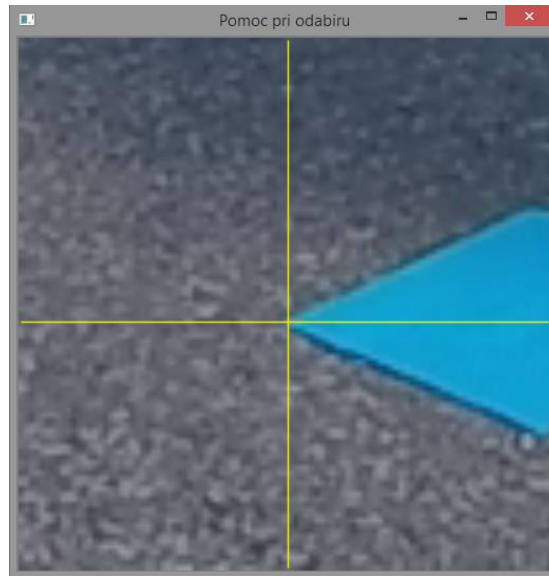


Fizički kalibracijski uzorak

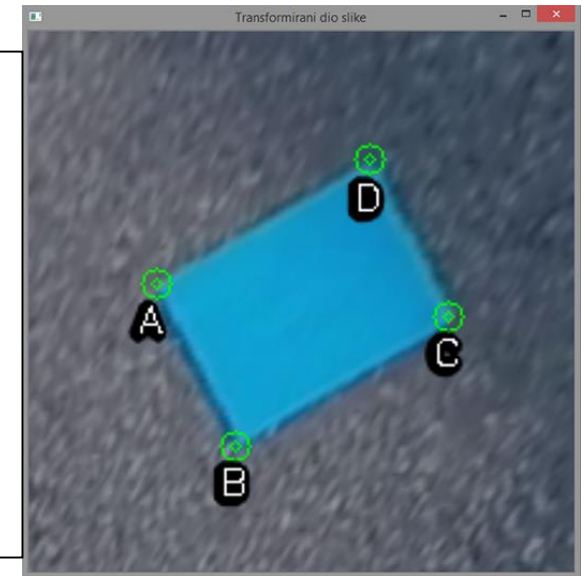
Eksperimentalni rezultati i problemi



Eksperimentalni rezultati i problemi



Izmjerena površina objekta : 615.313363234 cm ²
Stvarna površina objekta : 29.7 cm * 21.0 cm = 623.7 cm ²
Razlika površina objekta: -8.386636766 cm²
Pogreska izracuna površine : -1.34465877284 %
(točnost : 98.6553412272 %)
Stvarne udaljenosti između označenih vrhova :
Duzina = 29.7 cm
Visina = 21.0 cm
Izmjerene udaljenosti između označenih vrhova :
| AB | = 21.307 cm V Razlika : 0.307 cm(točnost : 98.538 %)
| AC | = 34.85 cm
| AD | = 29.152 cm D Razlika : -0.548 cm(točnost : 98.155 %)
| BC | = 29.483 cm D Razlika : -0.217 cm(točnost : 99.269 %)
| BD | = 37.281 cm
| CD | = 20.778 cm V Razlika : -0.222 cm(točnost : 98.943 %)



Eksperimentalni rezultati i problemi

	AB	AD	BC	CD	$\Delta AB $	$\Delta AD $	$\Delta BC $	$\Delta CD $	P	ΔP
R	21.00	29.7	29.7	21.0	0.00	0.00	0.00	0.00	623.7	0.00
1.	21.31	29.15	29.48	37.28	0.31	-0.55	-0.22	-0.22	615.31	-8.39
2.	20.89	28.99	28.90	20.75	-0.11	-0.71	-0.80	-0.25	602.54	-21.16
3.	20.49	29.71	30.04	20.46	-0.51	0.01	0.34	-0.54	611.78	-11.92
4.	21.09	29.51	29.63	20.96	0.09	-0.19	-0.07	-0.04	620.1	-3.6
5.	21.02	29.31	29.45	20.90	0.02	-0.39	-0.25	-0.10	615.58	-8.12
6.	21.33	29.41	29.39	21.30	0.33	-0.29	-0.31	0.30	625.99	2.29
7.	20.74	29.60	30.20	20.77	-0.26	-0.10	0.50	-0.23	620.00	-3.70
8.	20.46	29.49	29.36	20.76	-0.54	-0.21	-0.34	-0.24	606.23	-17.47
9.	20.17	30.05	30.0	20.84	-0.83	0.35	0.30	-0.16	615.59	-8.11
10.	20.41	29.99	30.09	20.9	-0.59	0.29	0.39	-0.10	617.3	-6.4
11.	20.63	29.85	30.00	21.48	-0.37	0.15	0.30	0.48	628.66	4.96
12.	20.75	29.99	29.52	20.99	-0.25	0.29	-0.18	-0.01	620.69	-3.01
13.	22.20	29.54	29.18	21.22	1.20	-0.16	-0.52	0.22	635.82	12.12
14.	21.01	30.06	27.24	22.57	0.01	0.36	-2.46	1.57	601.27	-22.43
15.	20.48	30.20	30.05	20.24	-0.52	0.50	0.35	-0.76	605.68	-18.02
16.	21.96	29.36	29.23	22.51	0.96	-0.34	-0.47	1.51	651.13	27.43
17.	21.01	29.79	30.2	20.14	0.01	0.09	0.50	-0.86	607.33	-16.37
18.	21.05	28.11	28.17	20.10	0.05	-1.59	-1.53	-0.90	577.88	-45.82
19.	20.27	32.33	28.93	22.27	-0.73	2.63	-0.77	1.27	648.27	24.57
20.	25.11	31.34	30.78	23.26	4.11	1.64	1.08	2.26	684.55	60.85
21.	19.08	29.68	28.44	23.31	-1.92	-0.02	-1.26	2.31	565.31	-58.39
Σ	21.02	29.78	29.44	22.05	0.02	0.08	-0.26	1.05	617.95	-5.75
	AB	AD	BC	CD	$\Delta AB $	$\Delta AD $	$\Delta BC $	$\Delta CD $	P	ΔP

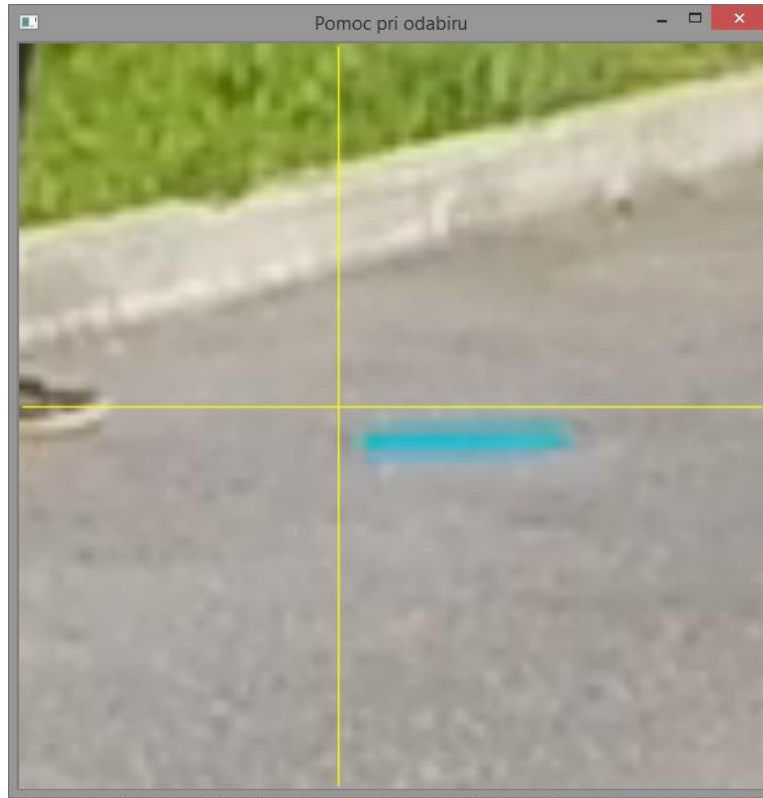
Narančastom označeni položaji s najvećim pogreškama

Najveća pogreška duljine: 4.11 cm
Najveća pogreška površine: 60.85 cm²

Položaji s najvećim pogreškama su relativno daleko od kamere

Položaji s minimalnim pogreškama su blizu kamere i kalibracijskog uzorka

Eksperimentalni rezultati i problemi



Kraj