Measuring Ball Spin by Image Registration

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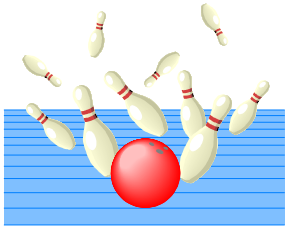
Background

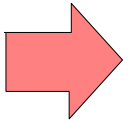
Many factors in sports :
score, time, weight, etc.



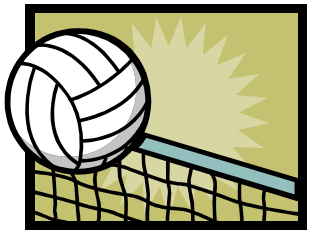




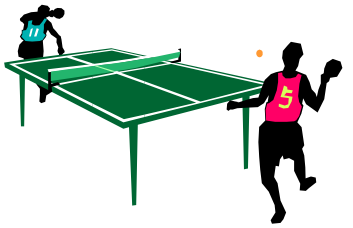
- considering condition
- measuring speed
- analysing player's motion
- understanding ball spin



usefull for training, improving skill





Spin of table tennis

- Football (free kick) 300-600rpm
- Baseball (curve) -1800rpm
- Golf 4000-10000rpm
- Tabel tennis -10000rpm

  up to 8094rpm for Chinese national team (Qun, 92)

2003/2/2

Spin of table tennis

- Football (free kick) 300-600rpm
- Baseball (curve) -1800rpm
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  up to 8094rpm for Chinese national team (Qun, 92)

- In 2000, ball diameter was changed from 38mm to 40mm to reduce spin and ball speel for making a game more entertaining

2003/2/2

Registration of known shape object

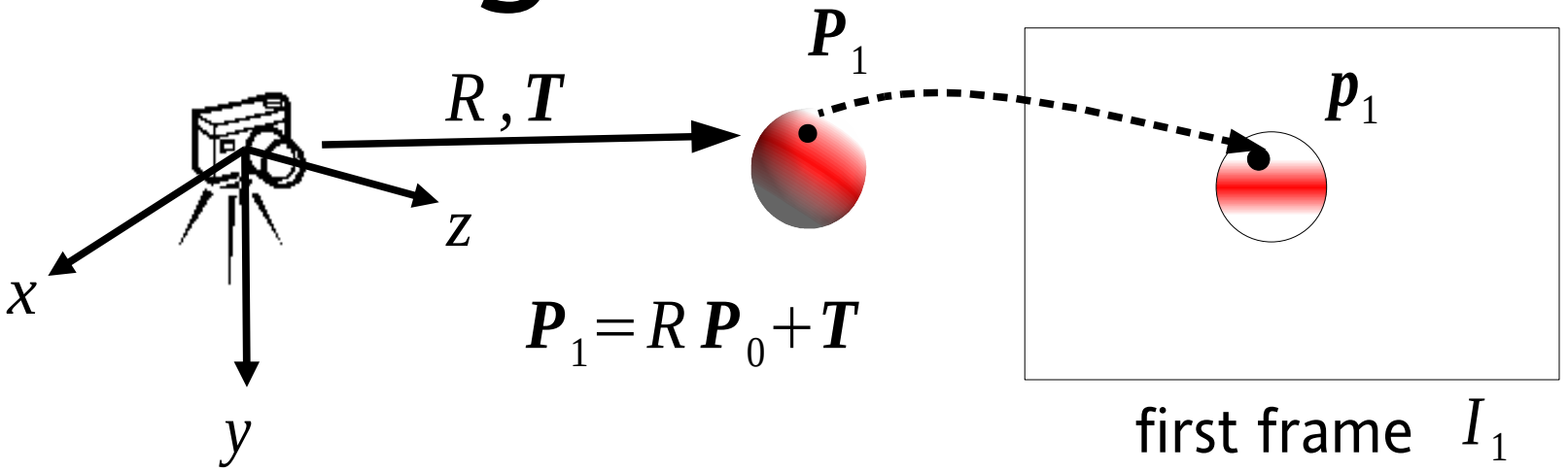
3D motion estimation with
two successive images
of a close-up marked ball

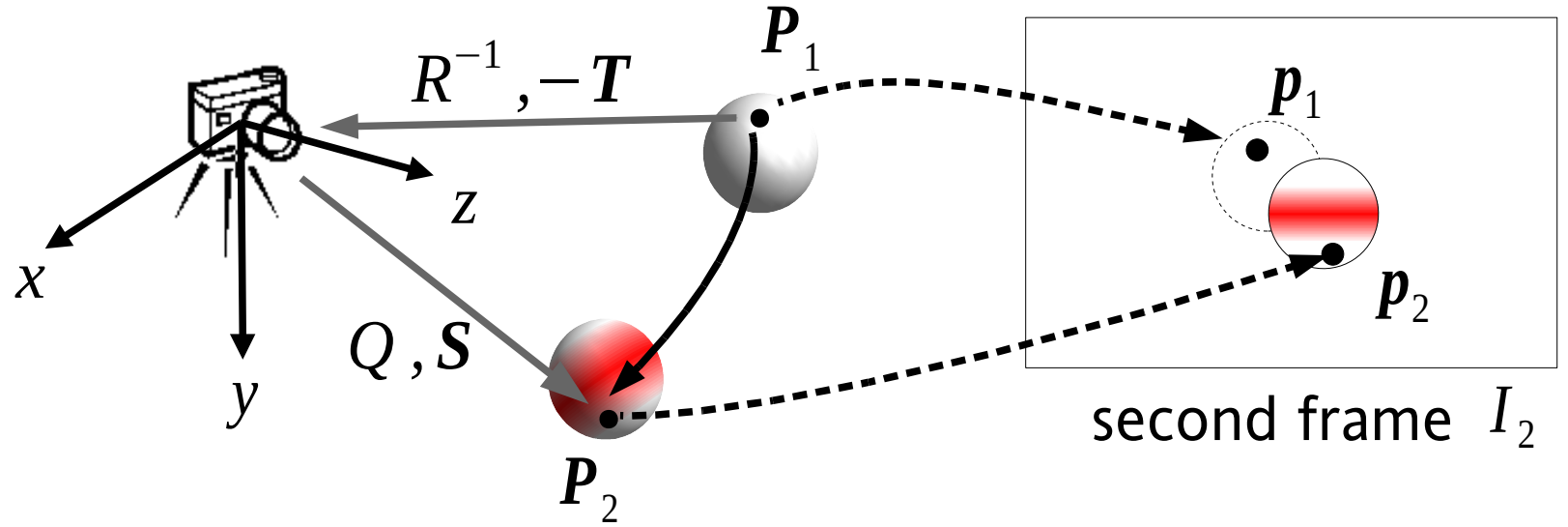
difference

Estimating spin (motion parameters)
that minimize the difference
between two images by IMAGE REGISTRATION

Assumption : the ball is a sphere (known shape)

Modeling transformations





Q, S : unknown parameters

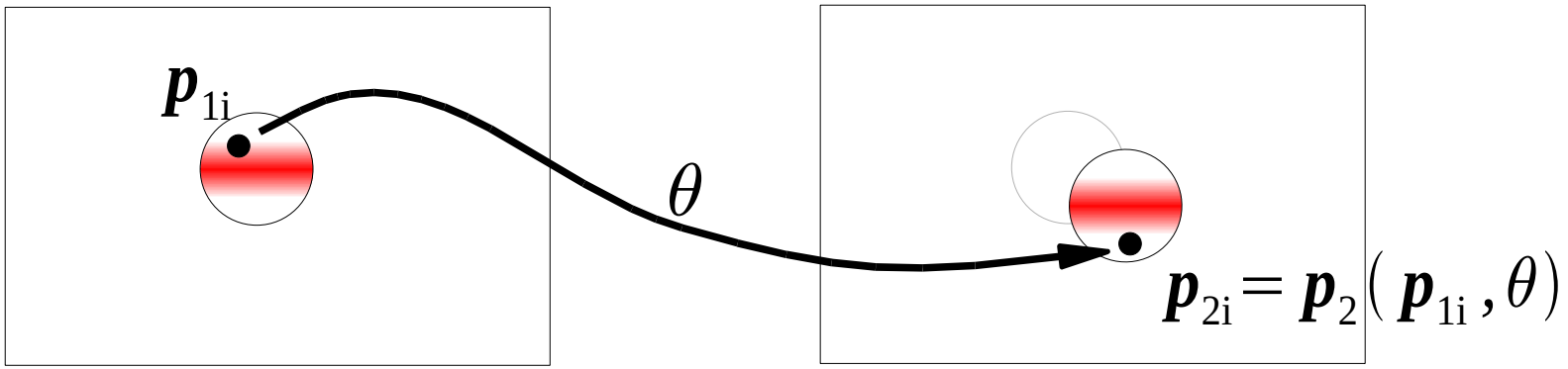
R, T : given parameters

$$P_2 = Q P_0 + S$$
$$= Q R^{-1}(P_1 - T) + S$$

Estimating parameters

minimize the sum of square of residuals:

$$\min_\theta \sum_i r_i(\boldsymbol{p}_{1\mathrm{i}})^2 \qquad r_i(\boldsymbol{p}_{1\mathrm{i}}) = I_1(\boldsymbol{p}_{1\mathrm{i}}) - I_2(\boldsymbol{p}_{2\mathrm{i}})$$



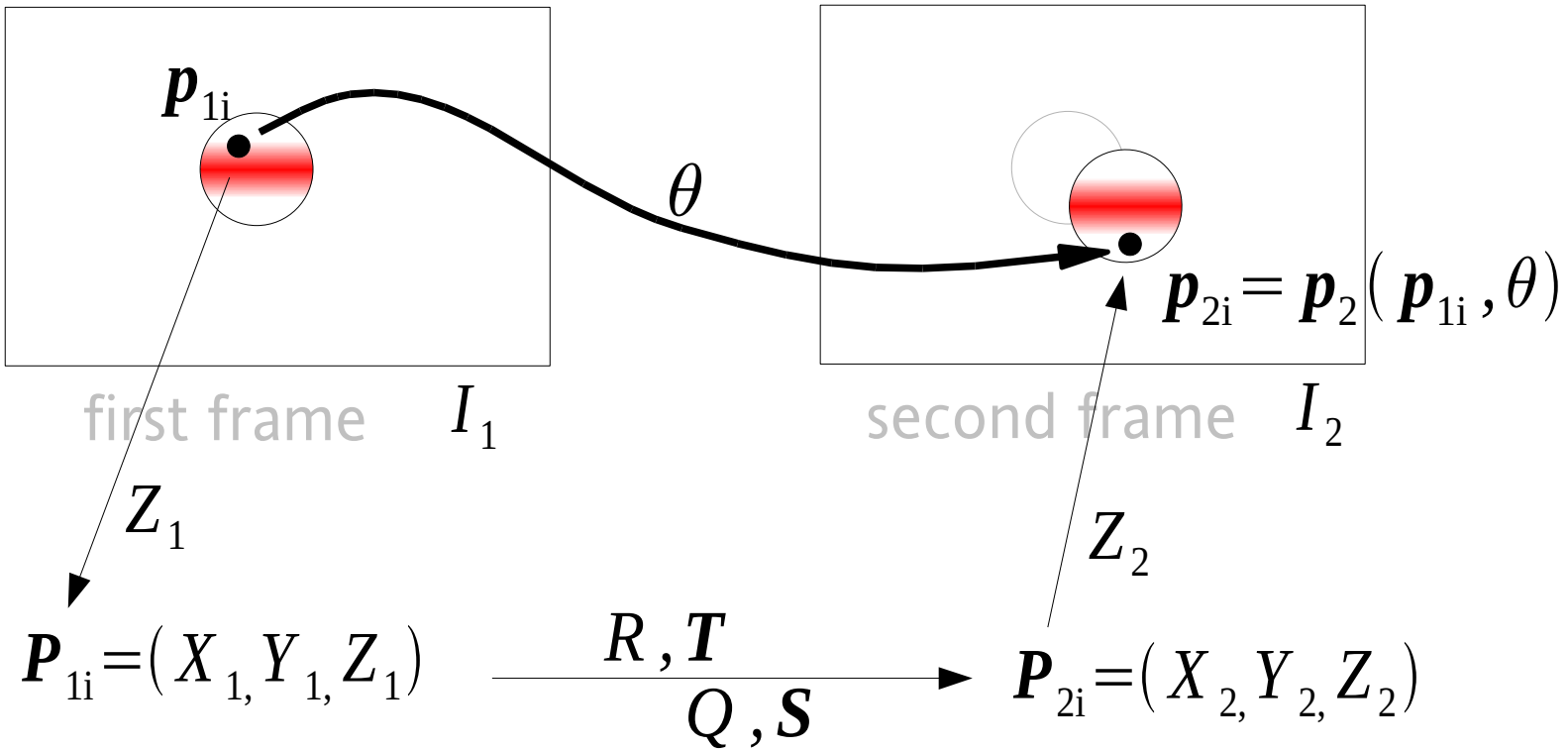
solved by the Gauss-Newton method:

to find the parameter $\theta = (Q, \boldsymbol{S})$

Estimating parameters

minimize the sum of square of residuals:

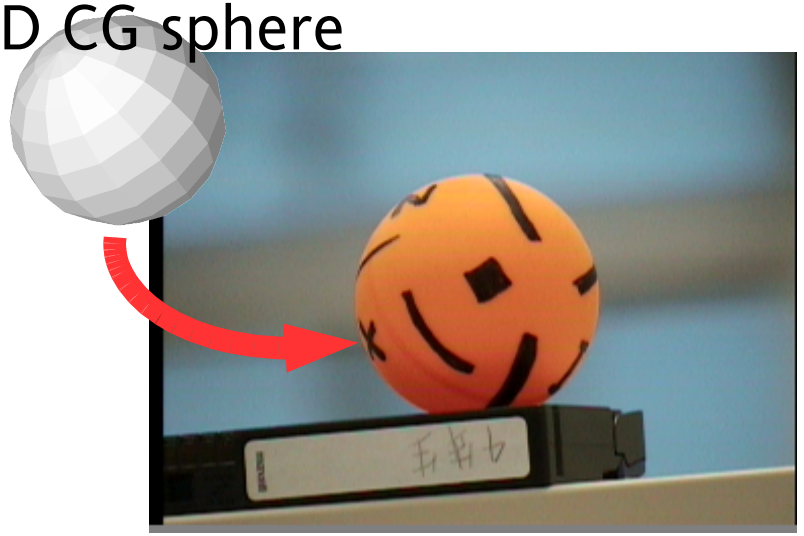
$$\min_\theta \sum_i r_i(\boldsymbol{p}_{1i})^2 \qquad r_i(\boldsymbol{p}_{1i}) = I_1(\boldsymbol{p}_{1i}) - I_2(\boldsymbol{p}_{2i})$$



Using depth buffer

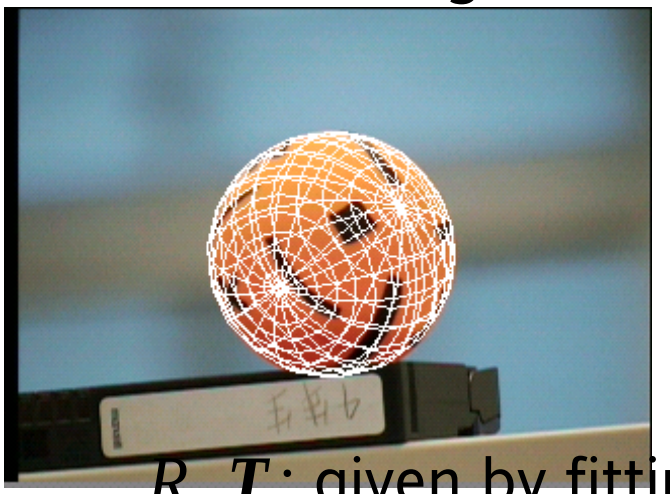
Transformation from $\boldsymbol{p}_{1i}$ to $\boldsymbol{p}_{2i}$ requires depth Z_1 Z_2 :

3D CG sphere

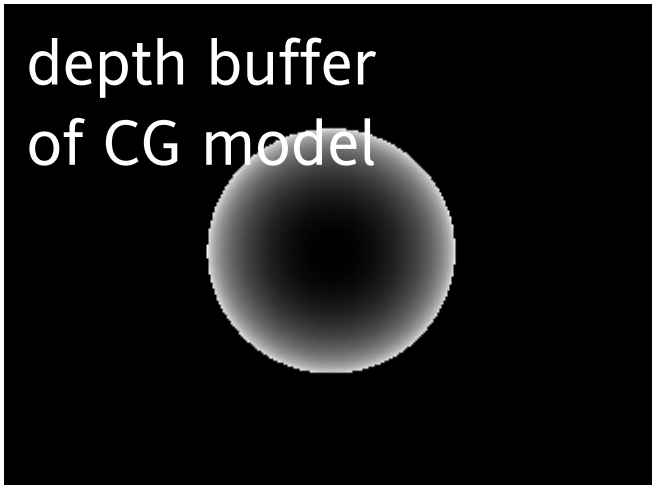


real image

manaul fitting



R , T : given by fitting

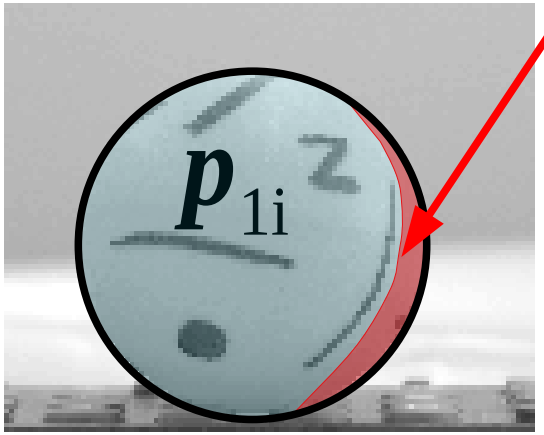


Z_1 is given by depth buffer,
then Z_2 is computed

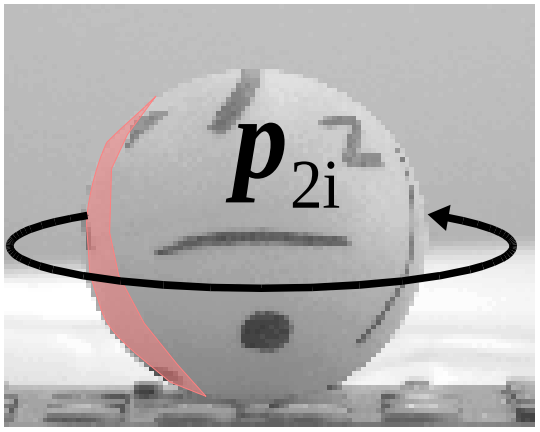
Visible test

Find the area for sum of residuals: where visible in both I_1 and I_2.

invisible area in I_2



first frame I_1



second frame I_2

surface normal at $\boldsymbol{p}_{2i}$ at I_2 :

$$\boldsymbol{N}_i = \frac{\partial \boldsymbol{P}_{2i}}{\partial x} \times \frac{\partial \boldsymbol{P}_{2i}}{\partial y}$$

angle between $\boldsymbol{N}_i$ and viewing direction :

$$\phi_i = \cos^{-1}\left(\frac{|\boldsymbol{N}_i \cdot \boldsymbol{P}_{2i}|}{|\boldsymbol{N}_i||\boldsymbol{P}_{2i}|}\right)$$

least square summation:

$$\sum_i r_i(\boldsymbol{p}_{1i})^2 \quad where \quad |\phi_i| > \frac{\pi}{2}$$

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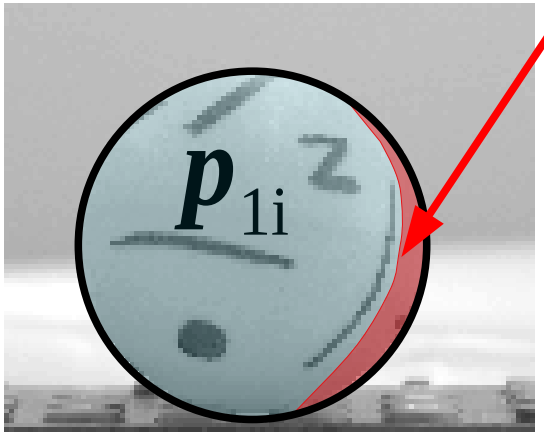

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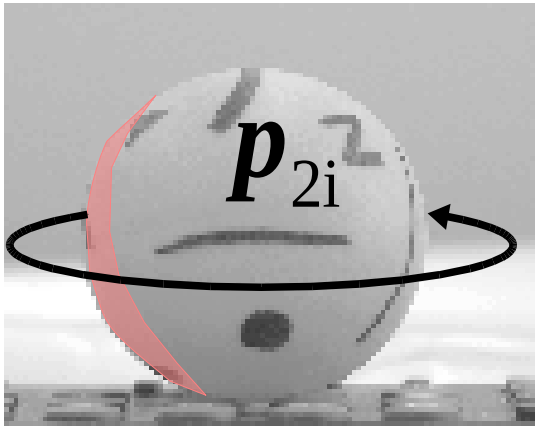
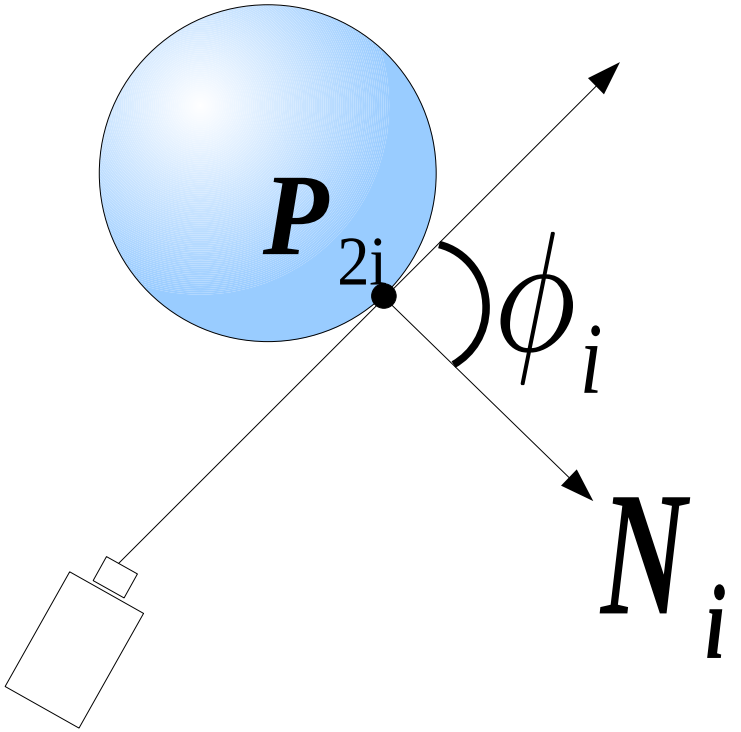


second frame I_2



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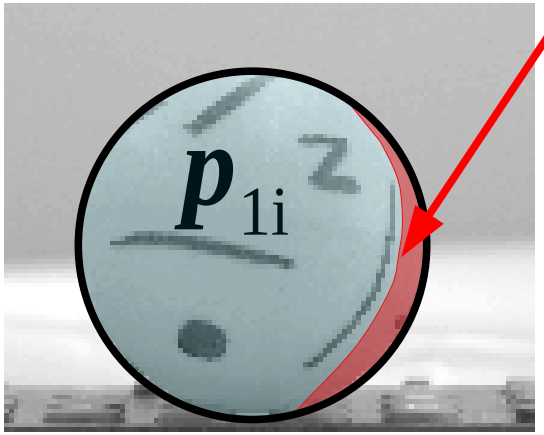
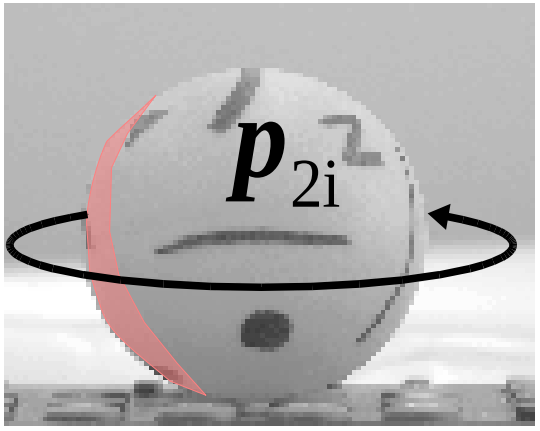
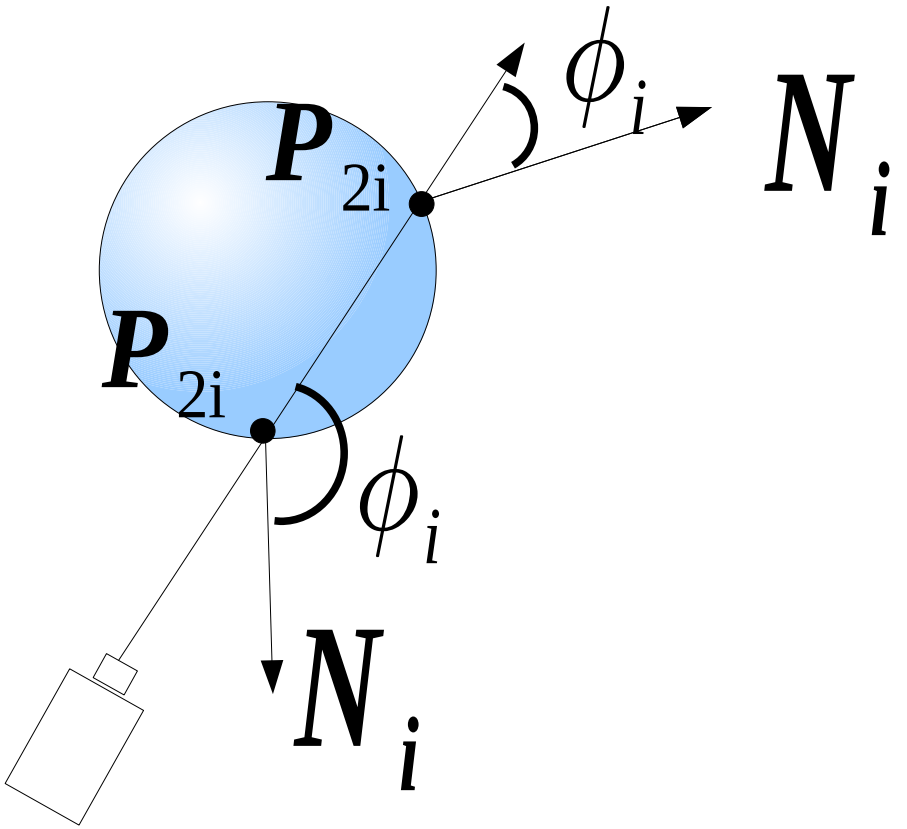


first frame I_1



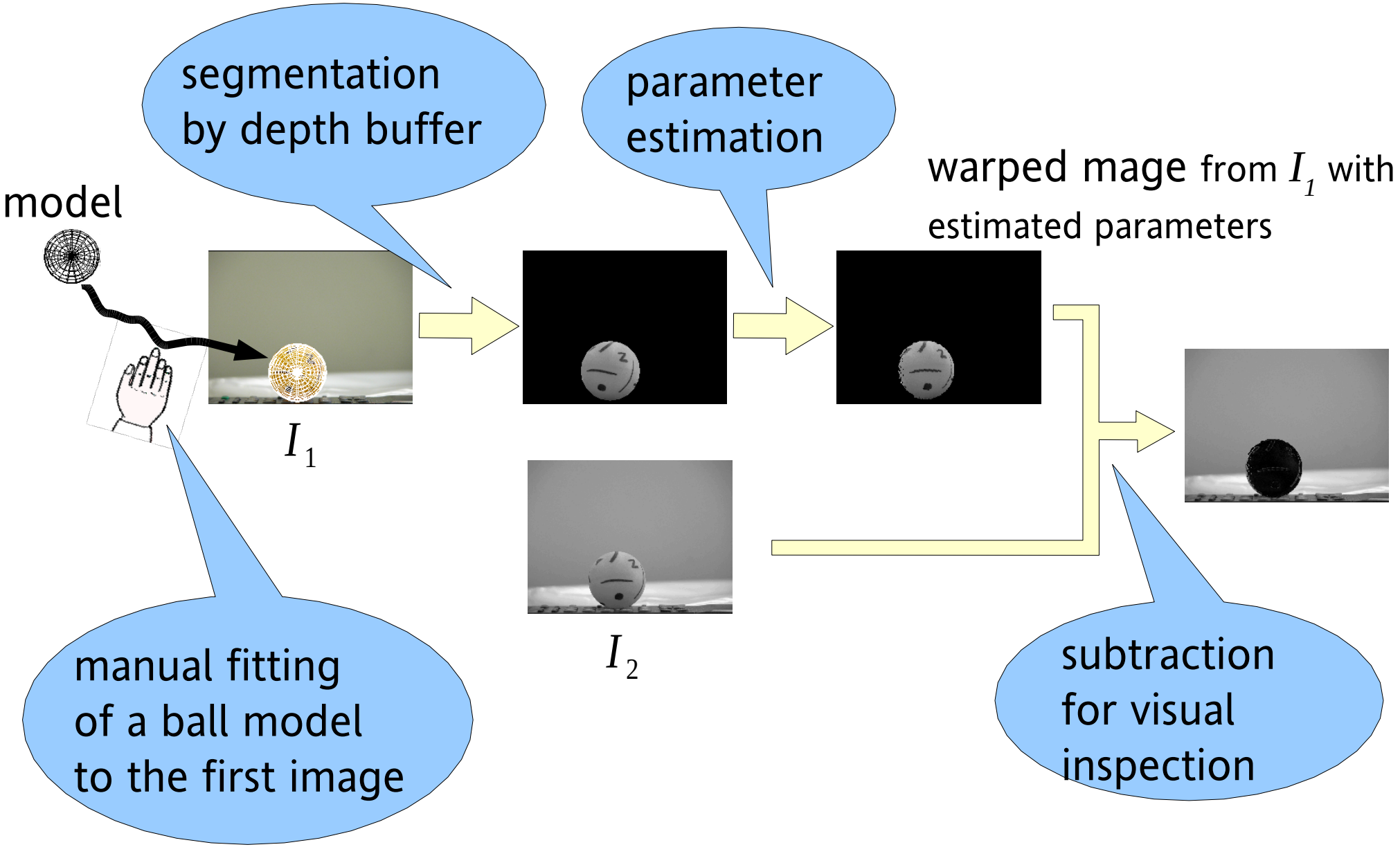
second frame I_2



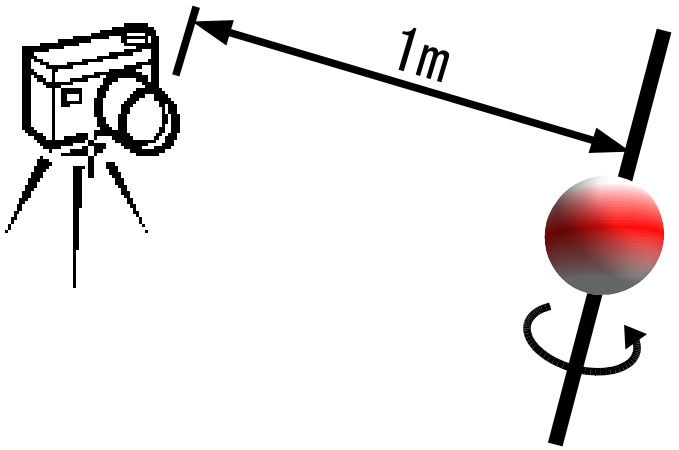
least square summation:

$$\sum_i r_i(\boldsymbol{p}_{1i})^2 \quad where \quad |\phi_i| > \frac{\pi}{2}$$

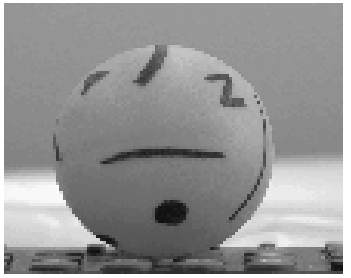
Overview of registration



Experiments



256×192

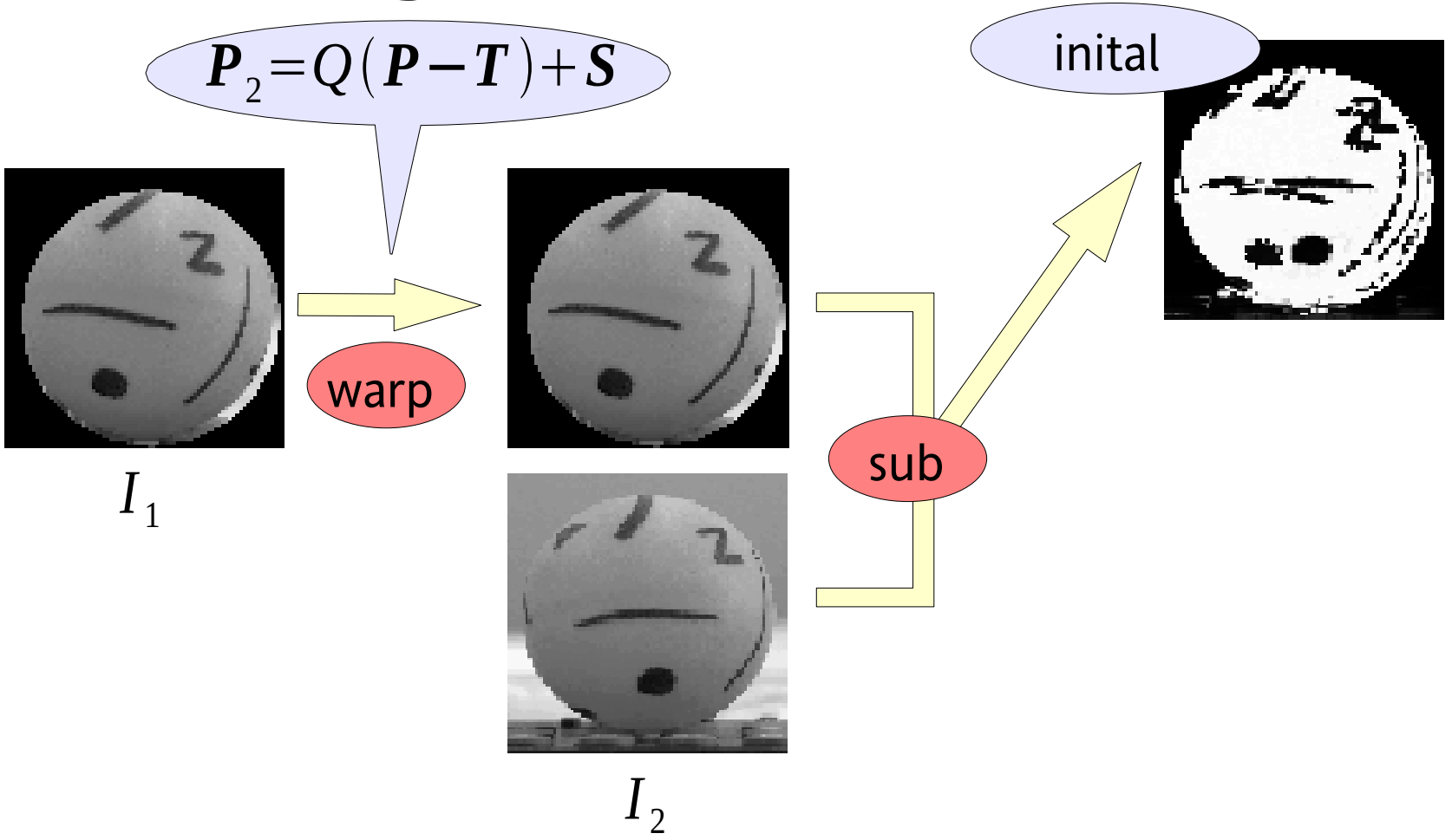


camera: Nikon COOLPIX5700

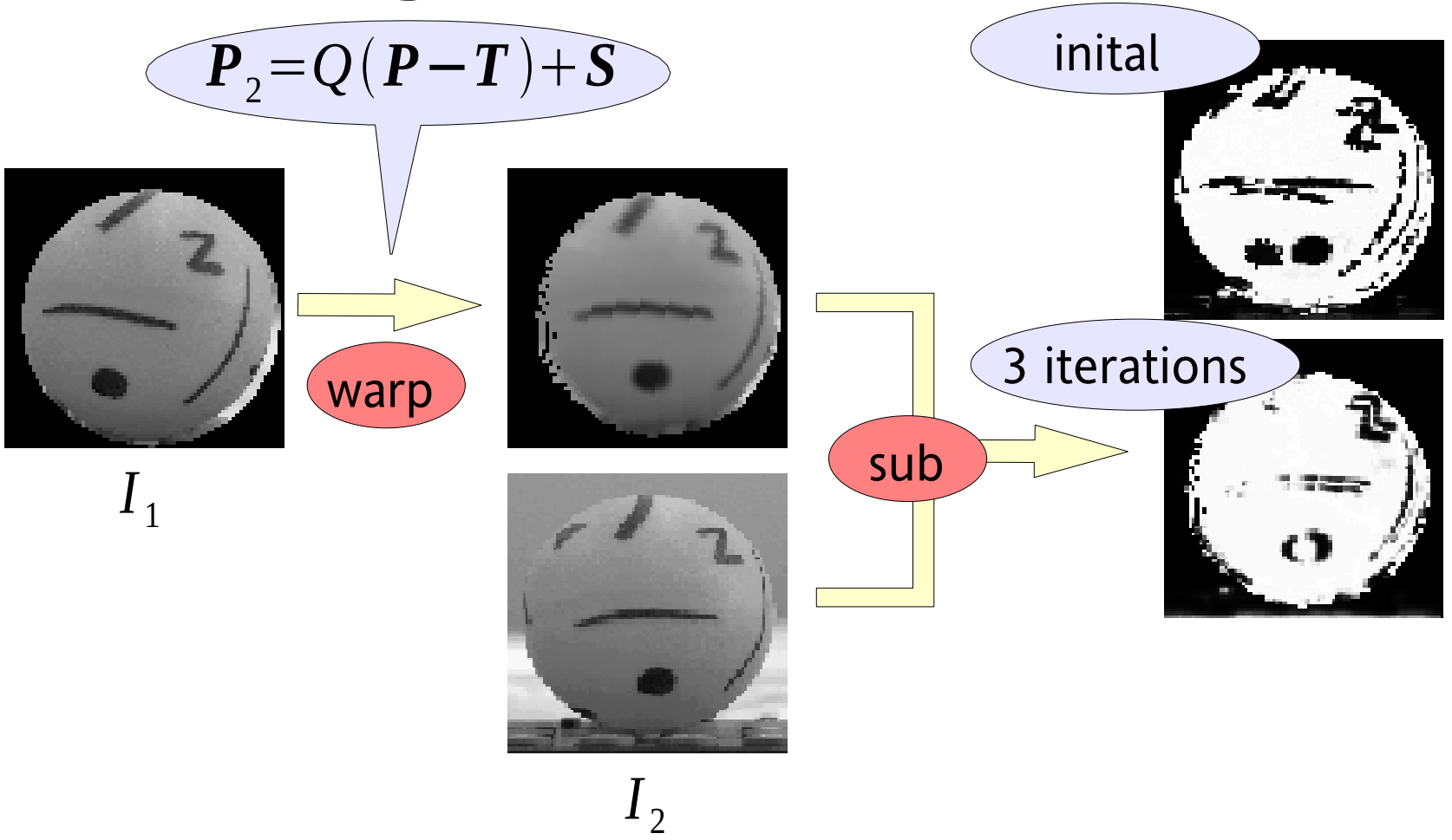
environment :

- table tennis ball (R=40mm) with ramdom marks at about 1.0 m distane away from the camera
- slightly rotated, moved away from the camera

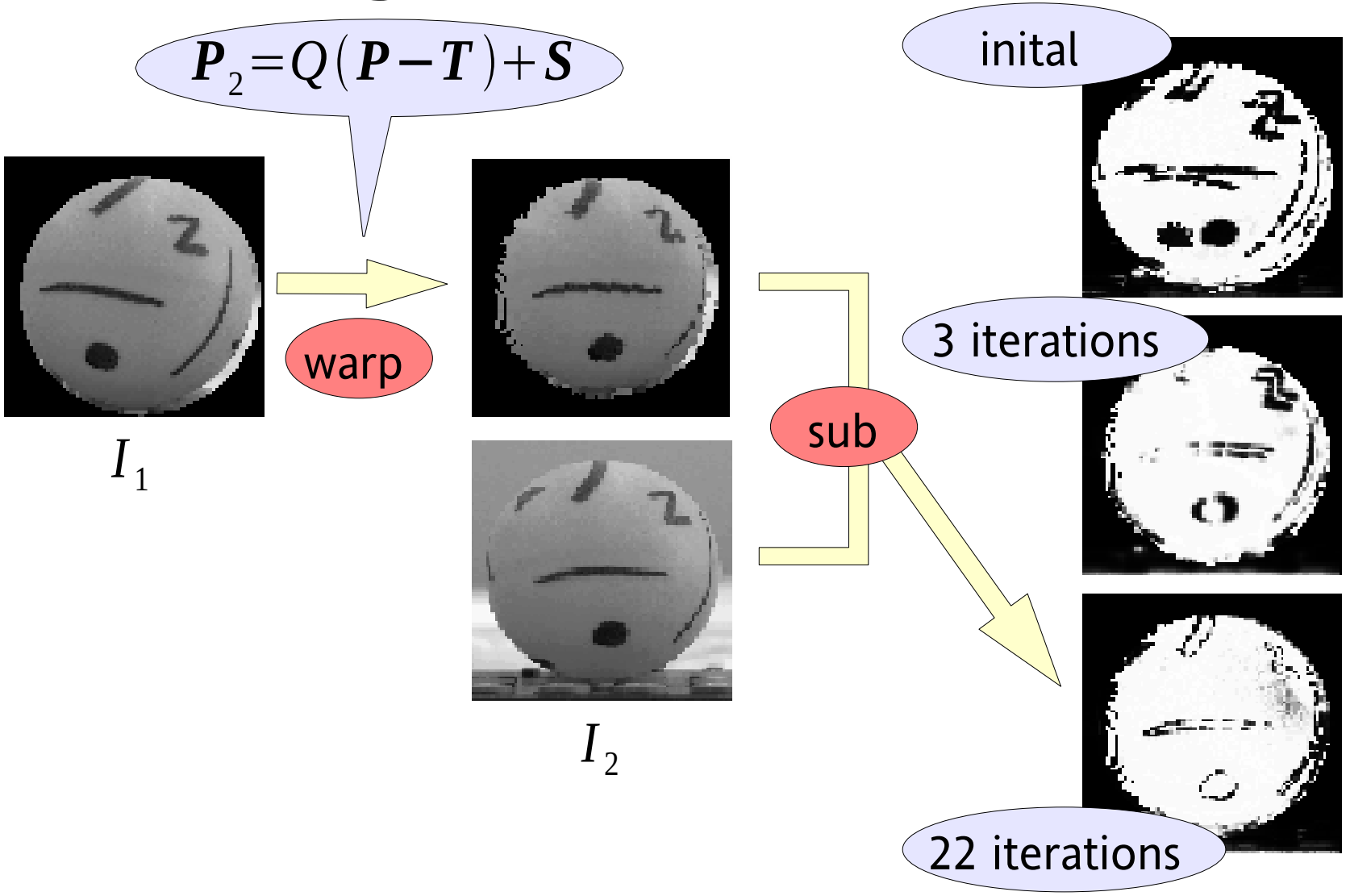
Convergence of estimation



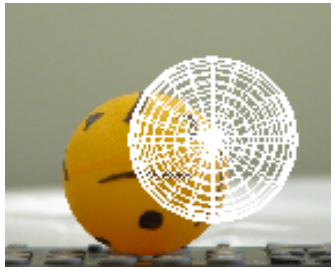
Convergence of estimation



Convergence of estimation

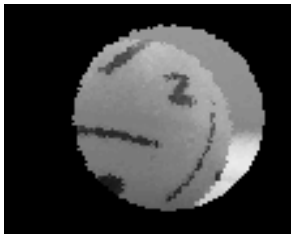


More improved estimation



rough
manual fitting

I_1

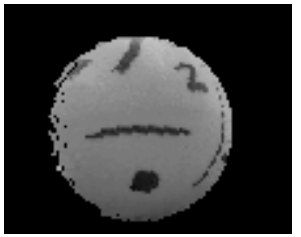


estimating R, T

warp

I_2

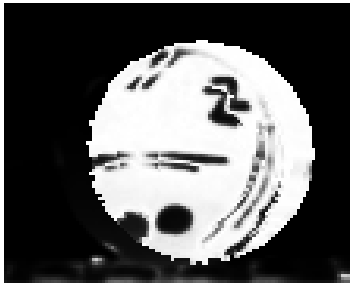
estimating Q, S



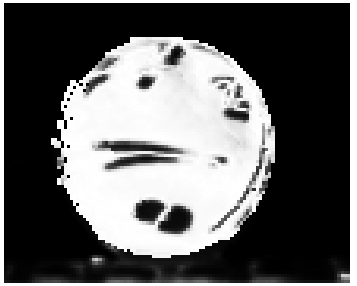
simultaneous estimation

sub

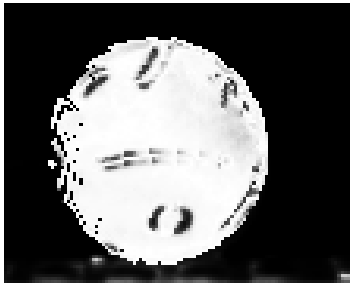
Experimental result



0 iterations

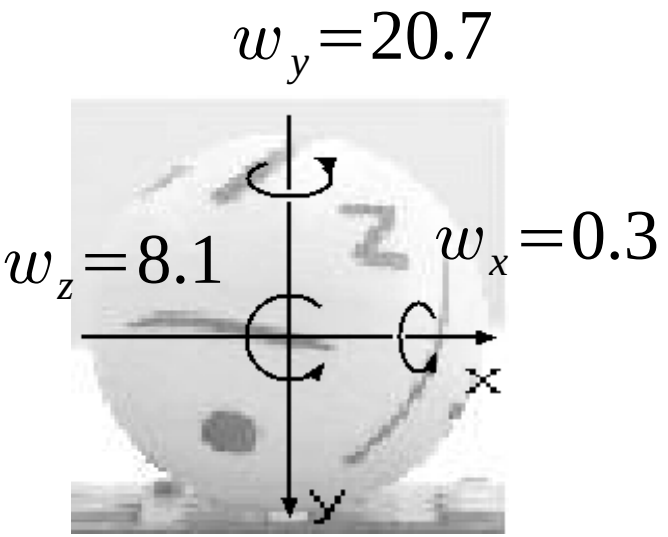


2 iterations



5 iterations

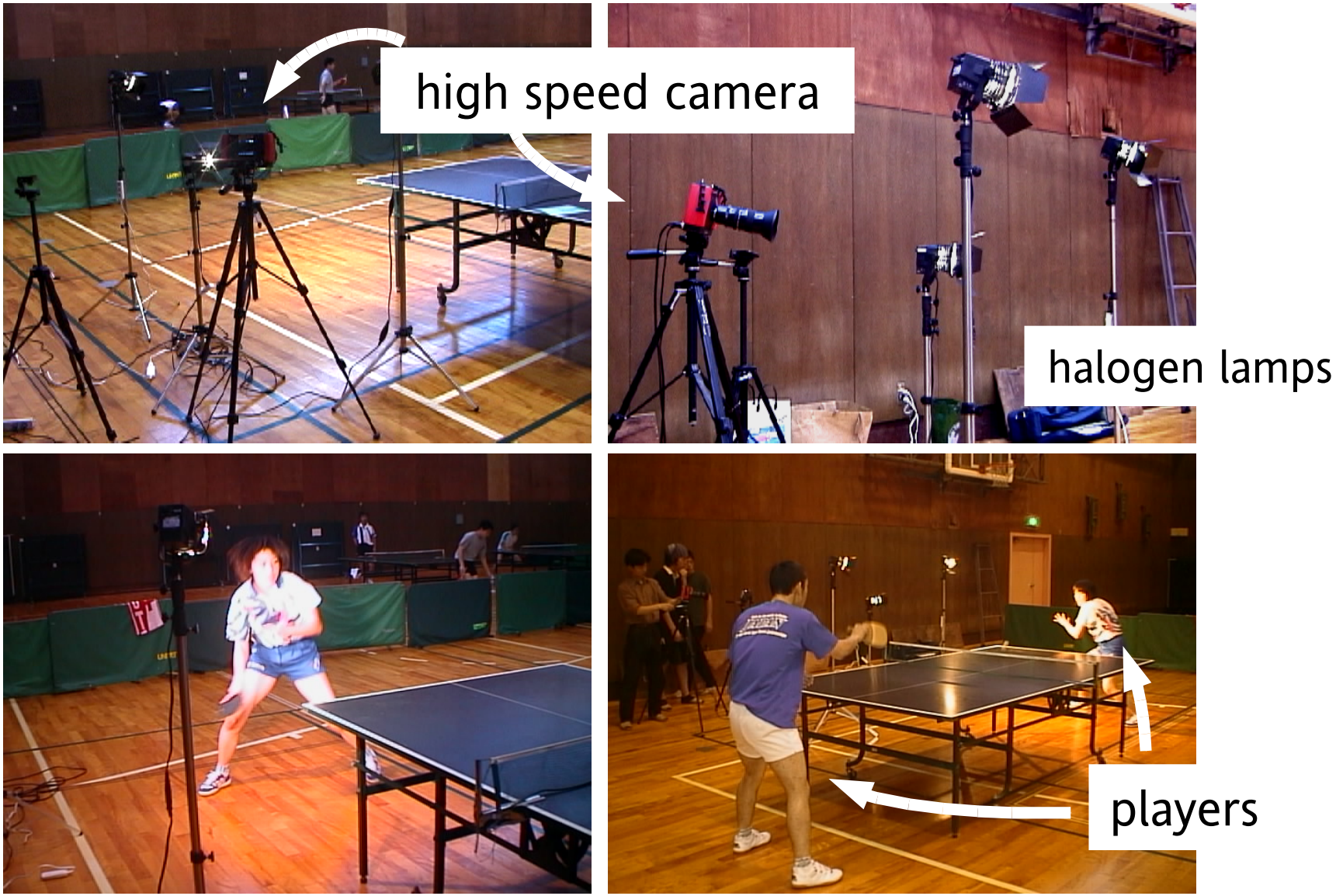
61 iterations



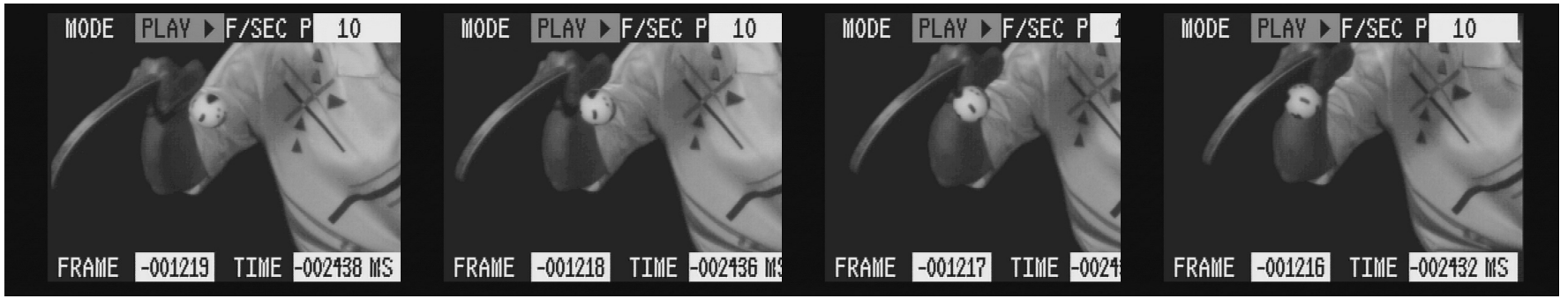
	Q [deg]			$\boldsymbol{T}$ [mm]			$\boldsymbol{S}$ [mm]		
	ω_x	ω_y	ω_Z	T_x	T_y	T_z	S_x	S_y	S_z
initial	0.0	0.0	0.0	-9.0	30.0	399.0	-9.0	30.0	399.0
estimated	0.3	-20.7	-8.1	-9.6	29.9	398.2	-10.1	29.5	401.2
(motion)							-0.49	-0.39	3.02

$(R = I)$

Real Rally of table tennis



Rally images of player A



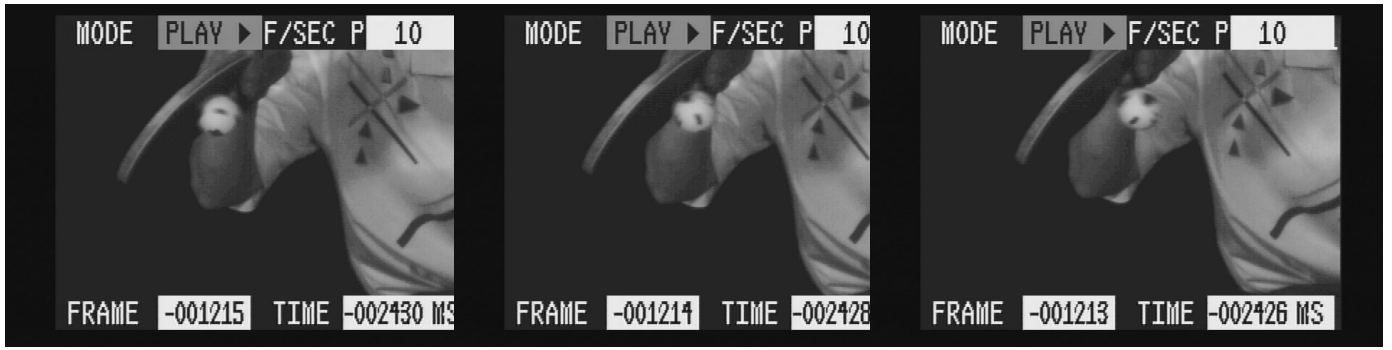
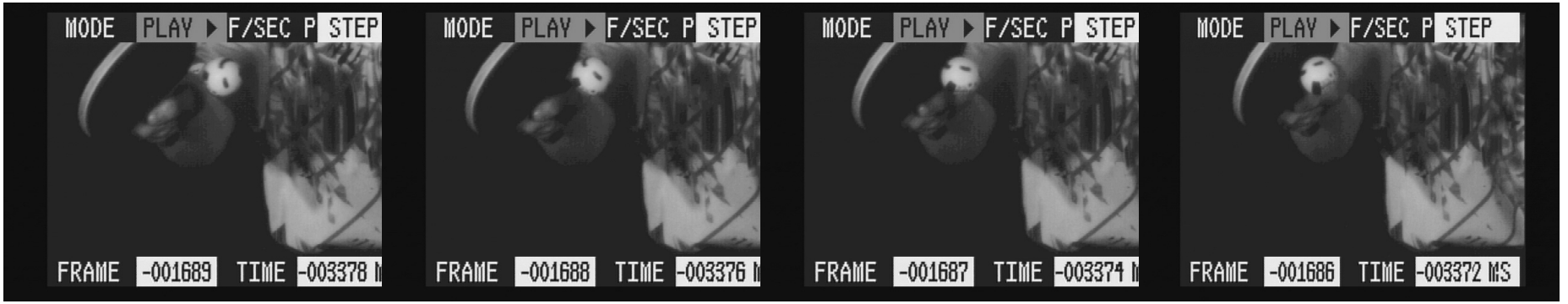


image sequence of table tennis rally
taken by a high speed camera (MotionMeter 500)
frame rate: 1/500 [s] shutter speed: 1/10000 [s]
resolution : 292x110 [pixel]

Rally images of player B



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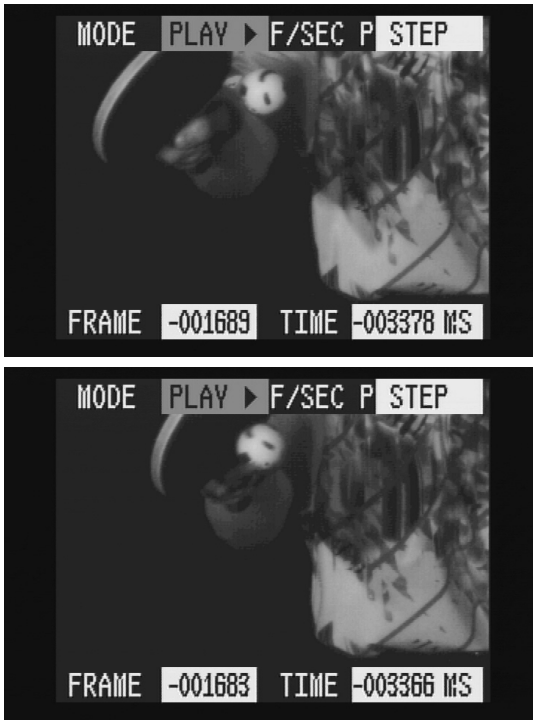

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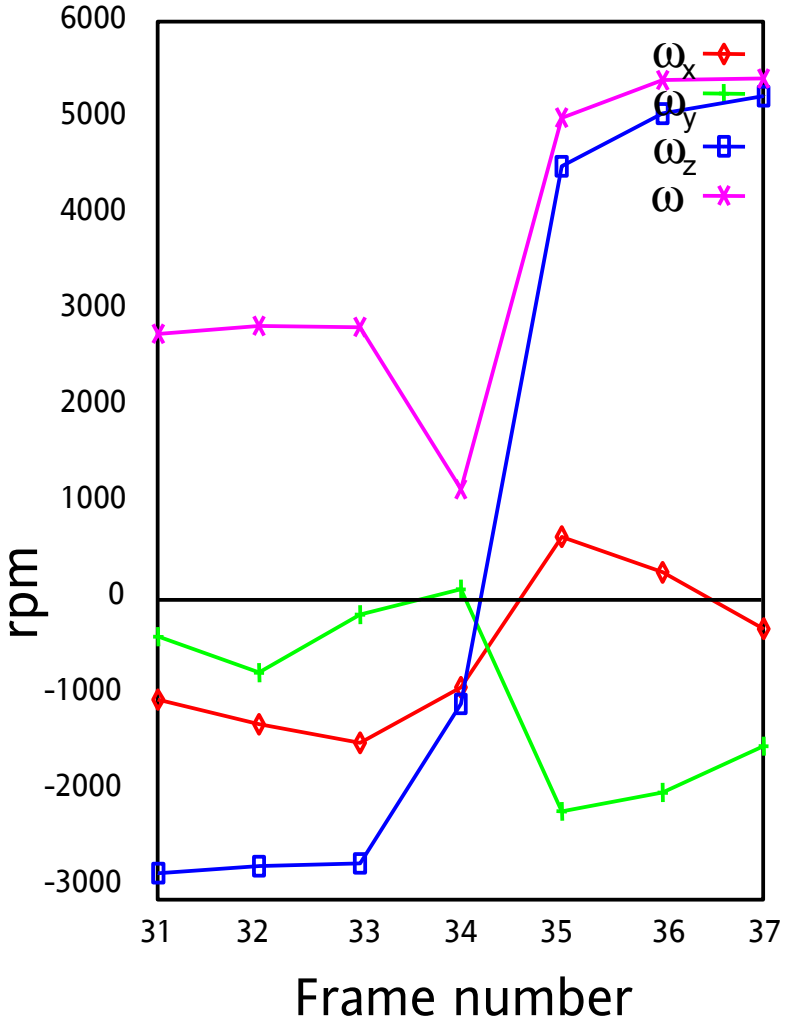
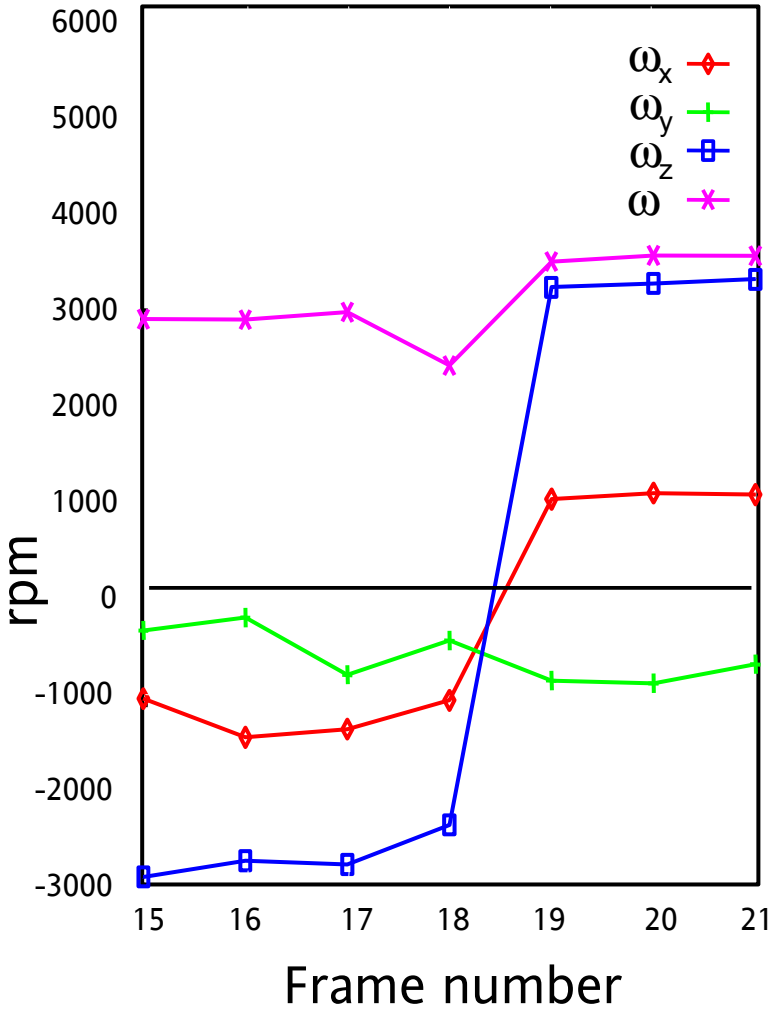
Spins of two players

sipn of player A



sipn of player B



Conclusions

- Proposed a method for measuring spin of table tennis ball by image registration with a known shape CG model
- Experimental results : two real images and real rally sequences. Not yet quantitative evaluation.
- DISADVANTAGE :
    1. focal lenghth should be known in advance
    2. simple shape for modeling object shape