Guide to answers for written examination in TSBB09 Image Sensors, 2018-01-11

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PART I: STANDARD CAMERAS & IR SENSORS

Exercise 1 For example:

- Geometric lens distortion
- Vignetting: (the image becomes darker towards the edges)
- Chromatic aberration: different wavelengths of the light have different diffraction index.
- Only 3D points in, or close to, the object plane are projected as sharp in the image plane.
- Decreased exposure time for a lens based camera, compared to an pin-hole camera, since more light enters through the aperture.

Exercise 2 See lecture A, slides 52 - 61.

Exercise 3 The object radiates thermal energy, but it also absorbs radiation from the other objects in the room. When the object's temperature is at 20°C, the temperature of the room, there is an equilibrium: them same amount of energy is radiated as is absorbed.

Exercise 4 For example:

- Thermal radiation that is reflected by the object.
- Thermal radiation emitted by the medium between the object and the camera (e.g. the air).
- Thermal radiation emitted by the camera itself.

Exercise 5 Glass absorbs a large range of the IR-spectrum, while germanium does not.

Exercise 6 In a CMOS sensor, each detector element is connected to the analog-to-digital converted by a random access principle, where the corresponding column a and row is selected for each detector element that should be read out. This means that, in principle, the read out can be made in arbitrary order, and even from only a smaller part of the sensor array. This is in contrast to a CCD sensor, where all measurements must be shifted out through the array in a pre-determined order.

Exercise 7

	0		0	
	1		1	
	3		3	

Rmaskimage

0	0	0	0	0
1	2	2	2	1
2	4	4	4	2
4	8	8	8	4
6	12	12	12	6

*Rmaskimage*w*

16

	1		1	
	1		1	
	1		1	

Rmask

.25	.25	.25	.25	.25
.25	.25	.25	.25	.25
.25	.25	.25	.25	.25
.25	.25	.25	.25	.25
.25	.25	.25	.25	.25

*Rmask*w*

0	0	0	0	0
1	2	2	2	1
2	4	4	4	2
4	8	8	8	4
6	12	12	12	6

Rimage

4

Exercise 8

- 4
- 1
- $\mathrm{SNR}_{\mathrm{DB}} = 10 \log_{10}(S/N) = 10 \log_{10}(127^2/5) = 35.1$.
- The sensor is saturated for intensities ≥ 255.

PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 See lecture F, slides 6, 11, and 19.

Exercise 10 See lecture F, slide 55.

Exercise 11 The two optical axes should be parallel, and perpendicular to the baseline. See lecture F, slide 39.

Exercise 12 α and β represent the scaling, along the horizontal and vertical dimensions, of the projection from the 3D scene to the image. Normally, we want a square that appears in front of the camera to look like a square also in the image, which therefore requires $\alpha = \beta$.

Exercise 13 First project the images to a sphere that is centered on the camera center $\mathbf{n}$. Then do the stitching on the surface of the sphere.

Exercise 14 Panorama stitching only works if the camera rotates around a fixed center. This is not the case for a general stereo pair, where the camera centers are located in two different points, point A and point B. Some details that appear in the A position will be obscured in position B and vice versa.

Exercise 15 See lecture F, slides 22 - 32.

Exercise 16 One end-point of the sword is at $(u_a, v_a) = (220, 460) \Rightarrow$

$$\begin{pmatrix} 7.6160 \\ 53.4751 \\ 1.8620 \end{pmatrix} = \begin{pmatrix} 0.0769 & -0.0002 & -9.21 \\ 0.0159 & 0.138 & -13.5029 \\ 0.0003 & 0.0022 & 0.784 \end{pmatrix} \begin{pmatrix} 220 \\ 460 \\ 1 \end{pmatrix} \Rightarrow$$

$$\begin{pmatrix} X_a \\ Y_a \\ 1 \end{pmatrix} = \begin{pmatrix} 7.6160 \\ 53.4751 \\ 1.8620 \end{pmatrix} /1.8620 = \begin{pmatrix} 4.0902 \\ 28.7192 \\ 1 \end{pmatrix}.$$

The other end-point is at $(u_b, v_b) = (400, 380) \Rightarrow$

$$\begin{pmatrix} 21.4740 \\ 45.2971 \\ 1.7400 \end{pmatrix} = \begin{pmatrix} 0.0769 & -0.0002 & -9.21 \\ 0.0159 & 0.138 & -13.5029 \\ 0.0003 & 0.0022 & 0.784 \end{pmatrix} \begin{pmatrix} 400 \\ 380 \\ 1 \end{pmatrix} \Rightarrow$$

$$\begin{pmatrix} X_b \\ Y_b \\ 1 \end{pmatrix} = \begin{pmatrix} 21.4740 \\ 45.2971 \\ 1.7400 \end{pmatrix} /1.7400 = \begin{pmatrix} 12.3414 \\ 26.0328 \\ 1 \end{pmatrix}.$$

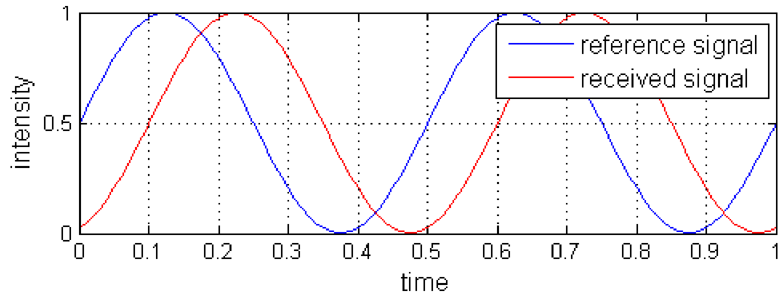
The length is therefore $\sqrt{(12.3414 - 4.0902)^2 + (26.0328 - 28.7192)^2} \approx 8.68$ dm.

PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 For example:

- A push-broom camera, e.g., used by a satellite or aircraft for making images/maps of the earth.
- A photo-finish camera.
- A scanner or photographic film, where the film passes by the camera. Same idea for a fax machine.
- A scanner of a items on a belt in an industrial manufacturing process.

Exercise 18 See figure. The phase difference between the reference signal and the received signal gives the time difference, which gives the range. There is an ambiguity in phase/time difference. In the figure, time difference can be 0.1 or 0.6.

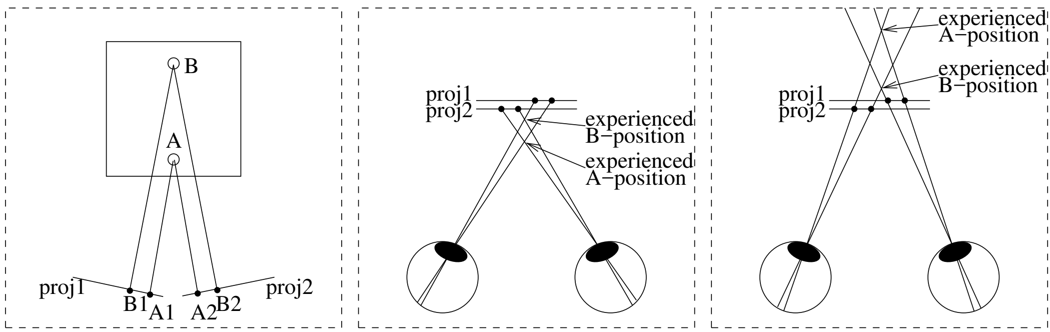


Exercise 19 See the following equation.

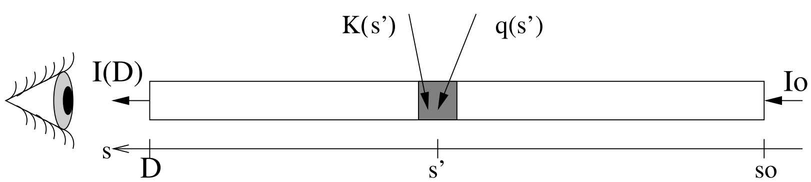
$$I = I_a\, k_d + I_l\, k_d \max(\mathbf{L} \cdot \mathbf{N}, 0) + I_l\, k_s\, [\max(\mathbf{R} \cdot \mathbf{V}, 0)]^n.$$

If $\mathbf{L} \cdot \mathbf{N}$ is negative, the surface is pointing away from the light source and is not illuminated by the light source. If $\mathbf{R} \cdot \mathbf{V}$ is negative, the reflected light is reflected in a direction away from the viewer. Consequently, in both cases the contribution to the intensity I should be zero.

Exercise 20 As seen in the middle and right figures, the brain matches the lines through A1 and A2. The cross-point gives the experienced depth of point A. Similarly, the brain matches the lines through B1 and B2 and the cross-point gives the experienced depth of point B. In the middle figure, A is correctly experienced to be closer than B. In the right figure, B is wrongly experienced to be closer than A.



Exercise 21 $\kappa(s)$ is the absorbtion function along a ray in the s-direction through the volume and $q(s)$ is the emission function along that ray.
The figure illustrates what was mentioned in the exercise.
Also, a volume element at $s = s'$ is marked, it can both absorb light $\kappa(s')$ and emit light $q(s')$.



Exercise 22 Below, the nescessary changes in the algorithm are marked in red.

For all projections at angles from $\beta = 0$ to 2π do:

- Take conebeam projections: $R_\beta(\gamma, z)$.
- Perform preweighting of the projections.
- Perform ramp-filtering.
- Perform backprojection along the conebeam rays.

Exercise 23 The volume can be approximately calculated with a double sum. (Compare with the Riemann sum.) See the pseudo code below. `Vol` is the result in mm^3.

```
Ydiff = zeros(45,50);
for m=2 to 45
    for n=1 to 50
        Ydiff(m,n)=Width(m,n)-Width(m-1,n);
    end;
end;
Vol = 0;
for m=1 to 45
    for n=1 to 50
        Vol = Vol + Ydiff(m,n) * (Range(n,m)-400) * 2;
    end;
end;
```

Exercise 24 See the figure. The four projections give four backprojected partial images which are summed to one resulting image.

backpro–jektion of: $\phi=0°$

0	−1	3	3	−1
0	−1	3	3	−1
0	−1	3	3	−1
0	−1	3	3	−1
0	−1	3	3	−1

$\phi=45°$

1	4	4	1	−1
−1	1	4	4	1
−1	−1	1	4	4
0	−1	−1	1	4
0	0	−1	−1	1

$\phi=90°$

−1	−1	−1	−1	−1
3	3	3	3	3
3	3	3	3	3
−1	−1	−1	−1	−1
0	0	0	0	0

$\phi=135°$

0	−1	1	1	4
−1	1	1	4	1
1	1	4	1	1
1	4	1	1	−1
4	1	1	−1	0

The backprojection result, the sum of the 4 images:

0	1	7	4	1
1	4	11	14	4
3	2	11	11	7
0	1	2	4	1
4	0	3	1	0