Guide to answers for written examination in TSBB09 Image Sensors, 2015-04-07

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PART I: STANDARD CAMERAS & IR SENSORS

Exercise 1 See lecture A, slides 64-72.

Exercise 2 See lecture A, slides 83-87.

Exercise 3 A 1D-sensor (one single row of pixels) that needs to be moved over the scene, or having the scene moved relative to. Can have high spatial resolution along the sensor and also high temporal resolution.

Exercise 4 The artifacts in question are color artifacts. Bayer images contain sample points from the red, green and blue content in the scene. The sample pattern of the various color channels are offset relative to each other. Intermediate sample points are interpolated. The result is not perfect due to approximate interpolation, e.g. linear interpolation. In fact, ideal interpolation might be impossible due to aliasing.

Exercise 5 The left sensor can have high spectral resolution (the sensor resolution in the vertical direction) and relative high temporal resolution compared to the right sensor. However, to produce a 2D image it must implement a push-broom sensor, i.e., must be moved over the object. The right sensor has only (in this example) 4 spectral bands, and they are not measured at the same time, i.e., a lower temporal resolution compared to the left sensor. Produces a full 2D image directly.

Exercise 6 Internal heat in the sensor will be detected as IR radiation, and mixed with the IR radiation from the objects in the scene.

Exercise 7 The amount of detected photons for each pixel is proportional to the pixel area, i.e., for the same amount of light into the sensor, and exposure time, each pixel will by able to detect fewer photons. The signal to noise ratio (SNR) of the detected signal relative to the shot-noise (pixel noise) is proportional to the mean number of detected photons. Consequently, the smaller the pixels are the larger is the pixel noise, given that everything else is the same.

Exercise 8 Consider a surface S on the object, at distance d from the sensor. The light from S that illuminates the image plane will be restricted to an area A, corresponding to an average intensity I. If we move the object to distance $2d$ from the sensor, in accordance to the physical law: only 25% of the previous amount of light will reach the sensor from S. On the other hand, the sensor area that is illuminated by this light is now 25% smaller than before, i.e., the average amount of light per area unit is, again, I.

PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 A rectified pair of stereo images have corresponding points on the same vertical coordinates, i.e., finding corresponding points is simplified. See lecture F, slides 39-50.

Exercise 10 A sphere mapping can include images in all directions in a similar scale. Contradictory, a flat mapping gets images with very different scale depending on direction.

Exercise 11 If the 3D point we want to triangulate is infinitely (or very) far away from the cameras, the corresponding projection lines become parallel. In this case there is no unique point that is at minimal distance to both projection lines, i.e., no solution can be determined.

Exercise 12 When the camera center moves from point A to point B, some points that appear in the A position will be obscured in position B and vice versa. Furthermore, you cannot determine which points appear in this way only by looking at a single image. Consequently, there is no geometric transformation of a picture that describes the change from position A to B.

Exercise 13 Alternative 3 is the correct one, see lecture F, slide 16.

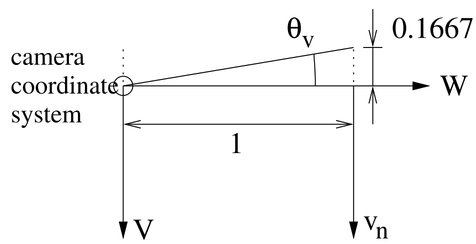
Exercise 14 The *outer parameters* are in $[\mathbf{R}\ \mathbf{t}]$. They depend on how the camera is *oriented* in relation to the world coordinate system.

Exercise 15 See lecture F, slide 32.

Exercise 16 The normalized image coordinate (u_n, v_n) is transformered to the real image coordinate $(u, v) = (275, 325)$ according to

$$\begin{pmatrix} 275 \\ 325 \\ 1 \end{pmatrix} = \begin{pmatrix} 500 & 0 & 500 \\ 0 & 450 & 400 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} u_n \\ v_n \\ 1 \end{pmatrix}.$$

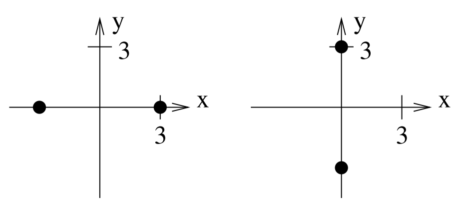
Solution to this equation system gives $(u_n, v_n) = (-0.4500, -0.1667)$. Therefore,
$\theta_u = \arctan(-0.4500/1) = -0.423 = -24.2°$ and
$\theta_v = \arctan(-0.1667/1) = -0.165 = -9.5°$, see figure.



PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 It is a type of omni-directional camera that use a combination of lenses and curved mirrors to obtain a large field of view. Se lecture J, slides 36-38.

Exercise 18 The most apparent object is given in the figure below, left. However, depending on the definition of the angle θ, the right suggestion for object, may also be a valid answer.



Exercise 19 The second principle is *Light pulse and time measurement.*
A light pulse is send out and the time t [s] it takes for it to come back is measured. Since $s = v \cdot t$ and $v = c = 3 \cdot 10^8$ m/s, the distance is $s/2 = c \cdot t/2$ [m].

Exercise 20 The random dot pattern contains unique surroundings along the epipolar lines, i.e. the autocorrelation is low for all shifts larger than the point size. Consequently, corresponding points can be detected using correlation.

Exercise 21 The white matte object is easy to measure. It reflects light well and in all directions, so that many rays will reach the camera.
The shiny metal object is more difficult to measure. The reflected light is weak in some directions, so there is a risk that to few rays will reach the camera.
The dark-grey matte object is more difficult to measure. The reflected light is weak in all directions, so there is a risk that to few rays will reach the camera.

Exercise 22 I_0 is the light entering from the background (behind the volume).
I is light leaving the volume entering the camera or eye.
L is the line of integration along the light path.
$\mu(x, y)$ is the absorbtion function of the volume.
The equation models how light is attenuated while traveling through an absorbing material.

Exercise 23 The program below calculates a depth-coded image `D(x,z)` and a maximum intensity projection (MIP) image, `M(x,z)`.

```
for z=-127 to 128
      for x=-127 to 128
            D(x,z):=256;
            y:=-127;
            do
                  D(x,z):=D(x,z)-1;
                  y:=y+1;
            while (f(x,y,z)<100 and y<128)

            M(x,z):=0;
            y:=-127;
            do
                  if (M(x,z)<f(x,y,z)) M(x,z):=f(x,y,z);
                  y:=y+1;
            while (y<129)
      end;
end;
```

Exercise 24 The figure illustrates the projection theorem. In the box with the question mark is a 1D Fourier transform in the r-direction. The function $f(x, y)$ corresponds to the object and $F(u, v)$ is its Fourier transform. The projection theorem states:
"The one-dimensional Fourier transform of a parallel projection $p(r, \phi)$ for an angle ϕ of $f(x, y)$, is identical to the function values along a radial line with the same angle ϕ in the two-dimensional Fourier transform $F(u, v)$".