Guide to answers for written examination in TSBB09 Image Sensors, 2023-01-09

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PART I: STANDARD CAMERAS & IR SENSORS

Exercise 1
The object plane consists of all points that appear sharp when projected through the lens onto the image plane.

Exercise 2
There is an attenuation of the image towards the edges of the image, proportional to cos^4.

Exercise 3
Photon noise is the randomness in signal associated with photons arriving at a detector. This photon counting process follows a Poisson distribution.

Exercise 4
CCD: Electric charge that is created in the light-measurement process is shifted along the lines and/or columns of the image to a site on the chip where charge can be converted to voltage and then measured and A/D-converted. All pixel data must pass through this point in order to read out an image.
CMOS: Electric voltage at each pixel can be connected though a column and row selection scheme to the measurement/conversion unit, in principle allowing random-access to every pixel cell.
(This is the a main advantage of CMOS transport, it is (in principle) possible to read out the pixels in any order. On the other hand, the relative long pathway from the pixel to the measurement/conversion unit introduces noise that can be avoided in the CCD transport.)

Exercise 5
The color channels W and C are wider than R and B.
(W= R+G+B and C=G+B.)
Therefore fewer photons are blocked, the detector will be more effective, and the SNR will be better.

Exercise 6
Arrangment with the shortest wavelength first:
• Ultra Violet (UV)
• Visible
• Near infrared (NIR)
• Shortwave infrared (SWIR)
• Midwave infrared (MIR)
• Longwave infrared (LWIR)

Exercise 7

a) The two curves show how much energy a surface radiates in different wavelengths, for two different temperatures. The higher curve, which peaks at a shorter wavelength, is for a higher temperature.

b) $k = 4$

c) ϵ_s is the emissivity. It is less than 1 for a greybody. (For a blackbody, the emissivity is equal to 1.)

d) It can be shown that the integral over Planck's law, for all wavelengths of a blackbody, gives that the total radiated energy is $W = \sigma T^4$, i.e. Stefan-Bolzmann's law.

Exercise 8

a) In the focal plane, the PSF is the squared Fourier transform of the aperture, i.e. $(G(\rho))^2$, also called the Airy pattern.

b) Here, the image is certainly out-of-focus. The out-of-focus PSF takes the shape of a scaled version the camera aperture, i.e. a circle.

PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9
The lines are still straight. It is not certain, however, that they are still parallel.

Exercise 10
Take an image of a scene with straight lines, resample it according to the given equation. Find a γ that makes the lines straight in the image too.

Exercise 11
$\mathbf{C}$ is a 3×4-matrix that can be determined up to a scale factor, i.e. 11 unknowns in $\mathbf{C}$ need to be determined. One corresponding point-pair on the 3D calibration object and the image, contributes with 2 equations to solve for $\mathbf{C}$. Consequently, the minimum number of 3D points on the calibration object is 6.

Exercise 12
???? = 901. The relation between pixel height and pixel width, $901/1132 = 1907/2397 = 0.796$, will not change during zoom.

Exercise 13
Use a blending weight function `alpha` that has smaller values at the edges of the image and larger values at the center. `Pano1` and `Pano2` are the two images transformed to the reference grid. `alpha1` and `alpha2` are the weight image (`alpha`) transformed to the reference grid. Perform normalized weighting:

$$\texttt{Pano} = \frac{\texttt{alpha1}\cdot\texttt{Pano1} + \texttt{alpha2}\cdot\texttt{Pano2}}{\texttt{alpha1} + \texttt{alpha2}}$$

This way the borders of the individual images will be invisible in the panorama.

Exercise 14
The translation vector $\mathbf{t}$ will change.
The rotation vector $\mathbf{R}$ remains the same.
A too-small tile size tricks solvePnP that the chessboard is smaller than it is in reality. Therefore, it is estimated that the chessboard is closer to the camera, giving a smaller $\mathbf{t}$.

Exercise 15
The camera coordinate system is transformed with

$$\mathbf{M} = \begin{pmatrix} 0.5 & -0.866 & 0 & 0 \\ 0.866 & 0.5 & 0 & 0 \\ 0 & 0 & 1 & 500 \\ 0 & 0 & 0 & 1 \end{pmatrix}.$$

Because transformation of a coordinate system with $\mathbf{M}$, corresponds to transform its coordinates with

$$\mathbf{M^{-1}} = \begin{pmatrix} 0.5 & 0.866 & 0 & 0 \\ -0.866 & 0.5 & 0 & 0 \\ 0 & 0 & 1 & -500 \\ 0 & 0 & 0 & 1 \end{pmatrix},$$

the desired matrix is

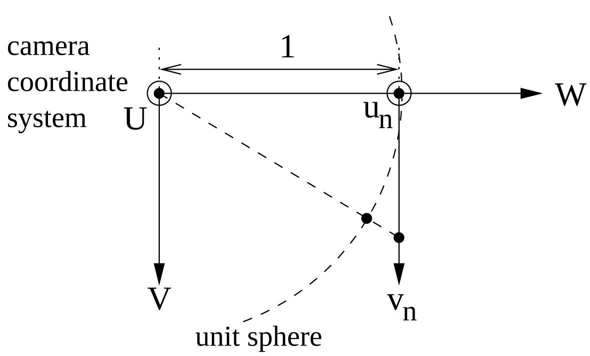
$$[\mathbf{R}\,\mathbf{t}] = \begin{pmatrix} 0.5 & 0.866 & 0 & 0 \\ -0.866 & 0.5 & 0 & 0 \\ 0 & 0 & 1 & -500 \end{pmatrix}.$$

Exercise 16
See figure. A homogeneous image coordinate $(u, v, 1)^T$ is transformed to a homogeneous normalized image coordinate $(u_n, v_n, 1)^T$ or equally to a camera coordinate $(U, V, W)^T$ as

$$(U, V, W)^T = (u_n, v_n, 1)^T = \mathbf{A}^{-1}(u, v, 1)^T$$

The corresponding projected coordinates on the 3D unit sphere will then be

$$(u_n, v_n, 1)^T / \sqrt{u_n^2 + v_n^2 + 1}.$$



PART III: NON-STANDARD IMAGE SENSORS

Exercise 17
It states how to orient the sensor to get perfect focus over the whole sensor area.

Exercise 18
The second principle is
2) Time-of-flight camera. Amplitude modulated light.
There are two variants. It is sufficient to describe one of them.
2a) Sinusoidal wave and phase shift measurement.
The light is amplitude modulated with a sine wave. It is sent out, reflected in the object and received. The phase of the received light is compared with a reference phase. The phase difference is proportional to the range.
2b) Pulsed ToF. (Also called Flash LIDAR, which is a confusing name.)
A rectangular pulse is sent out. The reflected light is measured in three short intervals (with a length equal to the light pulse length). An accurate time position is calculated based on these three values. The time is proportial to the range.

Exercise 19
C_t is the color or intensity of voxel number t and α_t is the opacity of voxel number t.

Exercise 20
Both provide a similar result. The *Blinn-Phong* model is simple and fast, but only partly based on a true physical model. The *Cock-Torrance* model is more complicated. It is completely based on a true physical model.

Exercise 21
f_k looks like a scaled version of the (approximate) aperture pattern. The size (scale) of f_k varies with k, which is proportial to the depth.
• Deblur locally by minimizing $|f_k * x - y|^2$.
• Search for best depths (k) in the local areas.
• Reconstruct all parts of the image.

Exercise 22
An HDR image can be produced from three images which have been captured with different exposure times.
V_0, the one with longest exposure time, will be saturated in bright areas, but dark areas will have good contrast.
V_1, the one with medium exposure time, will have good contrast for medium bright areas.
V_2, the one with shortest exposure time, will have good contrast in bright areas, whereas dark areas will be hardly visible.
V_{HDR}, the HDR image, can be created as the mean of the three images:

$$V_{\text{HDR}} = \frac{V_0 + V_1 + V_2}{3}$$

Exercise 23
A program is suggested below.

First, the maximum intensity of every column and the corresponding range value is calculated, i.e. $maxint(s)$ and $range(s)$.

Then a suitable threshold value, $thresh$, is calculated.

Finally, all range values that correspond to an intensity less than the threshold value is set to 0.

```
for s=1 to 512
      maxint(s):=0;
      range(s):=0;
      for r=1 to 512
            if (f(s,r) > maxint(s))
                  maxint(s):=f(s,r);
                  range(s):=r;
            end
      end
end

thresh = 0.5*mean(maxint));

for s=1 to 512
      if maxint(s) < thresh
            range(s):=0;
      end
end
```

Exercise 24

a) MPI occurs when light can take several paths from emitter to sensor: partly the direct path, partly indirect paths when the light bounces more than once in the scene. When the arrival time of the light is measured, the distance comes to be overestimated, if the light that has taken an indirect path is included in the measurement.

b) • Only the *ToF* camera has MPI. It emits many light rays in many directions at once. Then MPI, as described in a), may happen.
• At a certain time point, *Lidar* sends out a pulse in only **one** direction and then recieves in only **one** direction. It can therefore not get MPI.
• A *sheet-of-light* camera illuminates a line, and can therefore get light from indirect paths. However, the camera does not calculate distance from arrival time.