Information page for written examinations at Linköping University

Examination date	2023-01-09
Room (1)	U2(2)
Time	14-18
Edu. code	TSBB09
Module	TEN2
Edu. code name **Module name**	Image Sensors (Bildsensorer) Written examination (Skriftlig tentamen)
Department	ISY
Number of questions in the examination	24
Teacher responsible/contact person during the exam time	Maria Magnusson
Contact number during the exam time	073 804 38 67, 013-281336
Visit to the examination room approximately	15.15, 17.00
Name and contact details to the course administrator (name + phone nr + mail)	Ulrica Ericsson 013-282379 ulrika.ericsson@liu.se
Equipment permitted	Calculator: is allowed. The calculator must have emptied memories. Calculator models with the possibility of wireless communication or with the possibility of saving files / documents (equivalent to .pdf or photo) are not allowed. It is the student's responsibility to be able to, on request, show that the memory is empty, and that the calculator model used has no unauthorized functionality. Dictionaries: English to Another language
Other important information	
Number of exams in the bag	

Guide

The written examination consists of 3 parts, one part for each of the three course aims in the curriculum.

- Part I: standard image sensors, including IR
- Part II: geometry and multiple views
- Part III: non-standard image sensors

Each part consists of 6 exercises where the student should demonstrate ability to explain concepts, phenomena, etc (type A exercises), and 2 additional exercises that test a deeper understanding of various topics in the course, for example, in terms of simpler calculations (type B exercises).

Type A exercises give at most 1 point each. Type B exercises give at most 2 points each.

To pass with grade 3: At least a total of 4 points each in each of the three parts.

To pass with grade 4: At least a total of 6 points each in each of the three parts.

To pass with grade 5: At least a total of 8 points each in each of the three parts.

Write your AID code at the top of the pages in this examination thesis and any sheet appended to the examination thesis. Appended sheets must also have the course code and date written on them and be numbered.

You can write several answers on one sheet. However, write only on one side of the paper!

You can write your answers either in Swedish or English.

Good luck!
Maria Magnusson

AID code:

PART I: STANDARD & IR IMAGE SENSORS

Exercise 1 (A, 1p) **Image formation**
Explain the meaning of the *object plane* for a lens based camera.

Exercise 2 (A, 1p) **Image formation**
Describe the consequences of the $\cos^4$-law for image sensors.

Exercise 3 (A, 1p) **Image sensors**
One type of noise in a digital camera is called shot-noise (or photon noise). Describe the cause of this noise.

Exercise 4 (A, 1p) **Image sensors**
The CCD sensor and the CMOS sensor are principally different in the way that the pixel measurements are transported out from the pixel array. Explain this difference.

Exercise 5 (A, 1p) **Image sensors**
Color cameras typically use Bayer filters, with red (R), green (G), and blue (B) filters on top of the detector elements, see below.

R	G	R	G
G	B	G	B
R	G	R	G
G	B	G	B

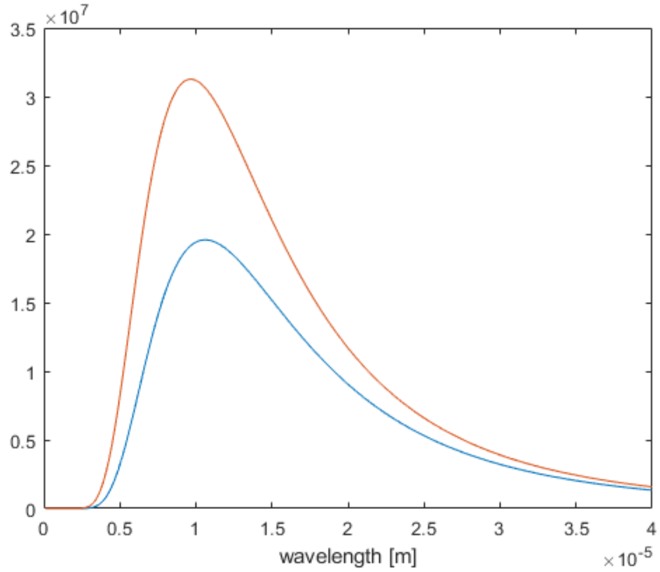
Another possibility is to use white (W), green (G), and cyan (C) filters instead. A disadvantage is (maybe) that post-processing is needed to convert to RGB.
But what is the advantage?

Exercise 6 (A, 1p) **Infrared and Multispectral Imaging**
The spectrum for electromagnetic radiation can be divided into different wavelength bands:

- Midwave infrared (MIR)
- Longwave infrared (LWIR)
- Visible
- Near infrared (NIR)
- Shortwave infrared (SWIR)
- Ultra Violet (UV)

Arrange these with the shortest wavelength first, followed by longer and longer wavelengths.

Exercise 7 (B, 2p) **Infrared and Multispectral Imaging**
The figure illustrates Planck's radiation law. Another related law is Stefan-Bolzmann's law, $W = \sigma T^k$, or $W = \epsilon_s \sigma T^k$, where k is a number.



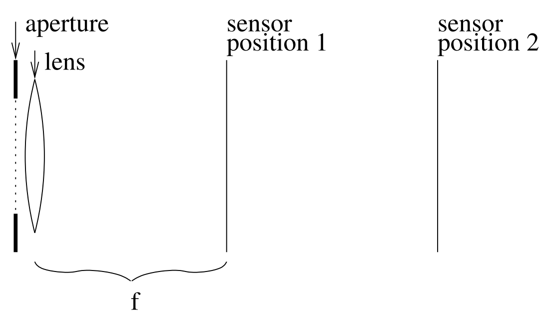
a) What is the physical difference between the two curves?

b) Which number is k in Stefan-Bolzmann's law above?

c) What does the introduction of ϵ_s in Stefan-Boltzmann's law implicate?

d) How are Planck's radiation law and Stefan-Boltzmann's law related? Specifically, how can Stefan-Boltzmann's law be obtained from Planck's radiation law?

Exercise 8 (B, 2p) **Image formation**



The figure shows an aperture and a lens and two positions of the sensor plane. f denotes the focal length. Suppose that the aperture is a circular box:
$g(r) = \Pi(r)$, where Π denotes the rectangular function and $r^2 = x^2 + y^2$.
Consequently, x and y are 2D Cartesian cordinates.
Moreover, the 2D Fourier transform of $g(r)$ is $G(\rho)$, where $\rho^2 = u^2 + v^2$.
Consequently, u and v are 2D Cartesian cordinates.

a) What is the point spread function at sensor position 1? Give an expression based on the information given in this exercise.

b) What is the point spread function at sensor position 2? It is enough to describe the shape with words.

AID code:

PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 (A, 1p)
Two parallel straight lines are transformed by a homography, How do they look after the transformation? Are they still straight or are they bent? Are they still parallel?

Exercise 10 (A, 1p)
You have a set of images from a camera with some amount of radial lens distortion that can be modeled as

$$r_{\text{correct}} = \frac{\arctan(r_{\text{distorted}} \cdot \gamma)}{\gamma}.$$

Describe a practical method for determining the distortion parameter γ with reasonable assumptions about the image content.

Exercise 11 (A, 1p)
An advantage with Zhang's method for camera calibration is that it only requires a simple 2D calibration pattern. An alternative to is to use a 3D calibration object and solve $\mathbf{C}$ in

$$s(u, v, 1)^T = \mathbf{C} \cdot (X, Y, Z, 1)^T = \mathbf{A}[\mathbf{Rt}] \cdot (X, Y, Z, 1)^T$$

It is then possible to extract $\mathbf{A}[\mathbf{Rt}]$ from $\mathbf{C}$ if desired. What is the minimum number of 3D points on the 3D calibration object in order to solve $\mathbf{C}$?

Exercise 12 (A, 1p)
A camera with optical zoom is calibrated for two different zoom settings, leading to two intrinsic camera matrices $\mathbf{A}_1$ and $\mathbf{A}_2$,

$$\mathbf{A}_1 = \begin{pmatrix} 1132 & 0 & 190 \\ 0 & ???? & 134 \\ 0 & 0 & 1 \end{pmatrix}, \quad \mathbf{A}_2 = \begin{pmatrix} 2397 & 0 & 195 \\ 0 & 1907 & 131 \\ 0 & 0 & 1 \end{pmatrix}.$$

Determine the element marked with question marks and motivate your choice.

Exercise 13 (A, 1p)
Explain how a blending weight function can be utilized in panorama stitching. Also mention why it is advantageous to use it.

Exercise 14 (A, 1p)
Is it possible to stich two images together in a panorama, if they are taken by two different cameras with different internal calibration matrices, $\mathbf{K}_1$ and $\mathbf{K}_2$? Motivate your answer!

Exercise 15 (B, 2p)
Assume that $\mathbf{x} = (X, Y, Z, 1)^T$ are the homogeneous coordinates of a point in the world coordinate system and that $\mathbf{y} = (U, V, W)^T$ are the coordinates of the point in the camera coordinate system. The relation between the two coordinates are

$$\mathbf{y} = [\mathbf{R}\,\mathbf{t}]\,\mathbf{x}.$$

Initially, the camera coordinate system and the world coordinate systems are aligned. The camera system is then rotated an angle $60°$ about the Z-axis, and finally translated so that the camera center ends up at position $(0, 0, 500)$ in the world coordinate system.
What is the $[\mathbf{R}\,\mathbf{t}]$ matrix after these transformations?

Exercise 16 (B, 2p)
In the computer exercise on constructing panorama images, you performed image stitching in spherical coordinates. In this case, how are homogeneous image coordinates $(u, v, 1)$ transformed to coordinates on the 3D unit sphere?
Hint: Use the camera calibration matrix $\mathbf{A}$ (denoted $\mathbf{K}$ in the panorama exercise) in your expression!

PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 (A, 1p) **Range cameras**
The following relation is called *Schempflug's condition*. What is the condition used for?

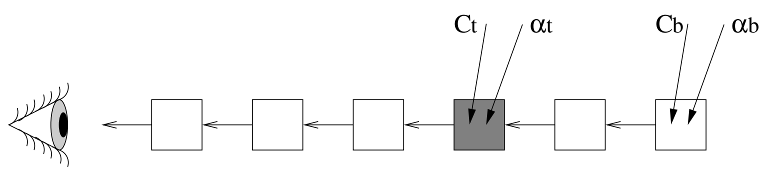
$$a_0 \tan\beta = b_0 \tan\alpha$$

Exercise 18 (A, 1p) **Range cameras**
Active range cameras can be based on
A) time-of-flight techniques or on
B) active light and triangulation.
For *time-of-flight*, there exists two different principles. The first is *1) Light pulse and time measurement, LIDAR.*
What is the second principle? Describe it briefly.

Exercise 19 (A, 1p) **3D vizualization**
In back-to-front compositing, the following iterative equations are used,

$$\begin{cases} C_b^b = \alpha_b C_b, \\ C_t^b = \alpha_t C_t + (1-\alpha_t) C_{t+1}^b. \end{cases}$$

Each voxel, at position t along the desired ray, has a corresponding value for C_t and an α_t, as illustrated in the figure. What is the physical interpretation of C_t and α_t?

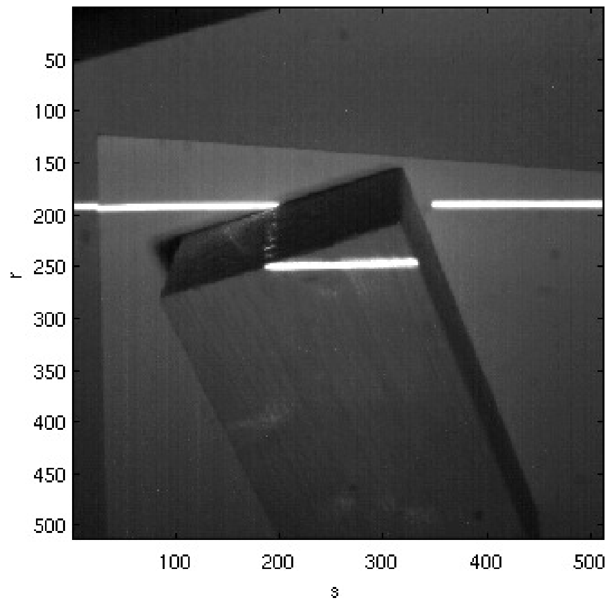


Exercise 20 (A, 1p) **3D vizualization**
Compare the two illumination models *Blinn-Phong* and *Cock-Torrance.* Describe the similarity and the difference between them.

Exercise 21 (A, 1p) **Specialized cameras**
Explain how a "coded aperture" can be used to extend the depth-of-field of a camera. Which mathematical operation is used to reconstruct a sharp image? Especially, explain how the equation $|f_k * x - y|^2$ is utilized.

Exercise 22 (A, 1p) **Specialized cameras**
Describe how to produce an HDR (high dynamic range) image from three different images. What is the difference between the three images? How should they be combined?

Exercise 23 (B, 2p) **Range cameras**
A raw image $f(s, r)$ from a sheet-of-light range camera is shown below.



From such an image, a raw range profile, $range(s)$, should be calculated. The image has some problems with laser occlusion (where the laser line is broken). These values should be located in the appropriate way for this type of range camera and set to 0.
The program below calculates the max intensity for every column, $maxint(s)$. Rewrite it so that it calculates $range(s)$ instead.

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

Exercise 24 (B, 2p) **Range cameras**

a) Explain the term multipath-interference (MPI).

b) Indicate which of the following sensor types have this problem. For each sensor, justify why it has or not has MPI.

   I) Lidar (e.g. Ouster OS-1)
   II) ToF-kamera (e.g. Kinect v2)
   III) Sheet-of-light laser triangulation