Information page for written examinations at Linköping University

Examination date	2022-01-10
Room (2)	E236(F)(14) FE244(1)
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)	Carina Lindström 013-284423 carina.e.lindstrom@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 your answers either in Swedish or English.

Good luck!
Maria Magnusson

PART I: STANDARD & IR IMAGE SENSORS

Exercise 1 (A, 1p) **Image formation**
The refraction index of the material in lenses is wavelength dependent and may cause distortion in the image. What is the name of this distorsion and how does it affect the quality of the image?

Exercise 2 (A, 1p) **Image sensors**
Why are digital camera chips sometimes equipped with micro lenses?

Exercise 3 (A, 1p) **Image sensors**
Exposure and read-out for a CMOS camera comes in two variants, global shutter and rolling shutter. Which of them may cause the so called Jello effect? Also, describe the origin of this effect.

Exercise 4 (A, 1p) **Infrared and Multispectral Imaging**
Why is the optics of a IR-sensor be made of rather expensive materials, such as germanium?

Exercise 5 (A, 1p) **Infrared and Multispectral Imaging**
What is the fundamental difference between the following images?
- An RGB color image
- A multispectral image
- A hyperspectral image

Exercise 6 (A, 1p) **Infrared and Multispectral Imaging**
Digital cameras, and in particular infrared sensors, can have a significant amount of *fixed pattern noise*. Describe what this is.

Exercise 7 (B, 2p) **Image sensors**
A small Bayer image with a corresponding Bayer pattern are shown below (left). Explain in detail how to convert the Bayer image to an RGB color image. Compute the result for the green (G) color plane, using normalized averaging with the interpolation kernel w shown below (right). Assume that pixels outside the image are zero.

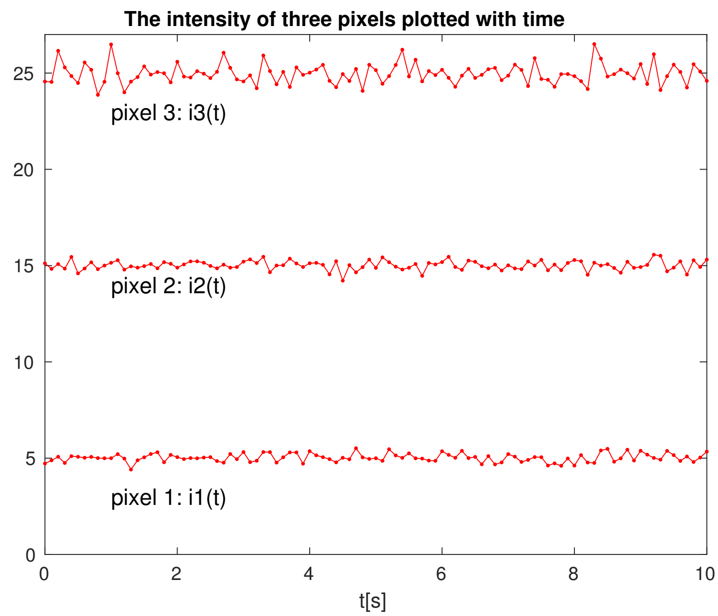
0	0	0	0	0
0	0	1	0	0
0	1	2	1	0
1	2	3	2	1
0	0	0	0	0

G	R
B	G

$$w = \frac{1}{4}\begin{bmatrix}1\\2\\1\end{bmatrix} * \frac{1}{4}\begin{bmatrix}1 & 2 & 1\end{bmatrix} = \frac{1}{16}\begin{bmatrix}1 & 2 & 1\\2 & 4 & 2\\1 & 2 & 1\end{bmatrix}$$

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

The figure below shows a diagram, where the intensity for three pixels in a camera sensor, $(i1(t), i2(t), i3(t))$, are measured for 101 time instances. With this data, the variances of the pixel intensities are estimated as $\mathrm{var}(i1) \approx 0.05$, $\mathrm{var}(i2) \approx 0.05$ and $\mathrm{var}(i3) \approx 0.25$.



- For pixel 1, calculate the SNR $= S/N$, where S and N are the signal and noise effects, respectively.
- One of the measurements for pixel 2 and pixel 3 is correct, and one is wrong. Which one is wrong? Motivate our answer with appropriate calculations.
  Hint: Remember that shot noise (photon noise), is the dominating noise source for camera sensors.

PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 (A, 1p)
The following matrix describes a homography,

$$\mathbf{H} = \begin{pmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & 1 \end{pmatrix}.$$

Giva another matrix that describes exactly the same homography.

Exercise 10 (A, 1p)
A camera with image size 1000×600 pixels has the following camera calibration matrix:

$$\mathbf{A} = \begin{pmatrix} 1000 & 0 & 499.5 \\ 0 & 990 & 299.5 \\ 0 & 0 & 1 \end{pmatrix}.$$

What is $\mathbf{A}$ if the camera zooms in with a factor of 2. Assume that the optical axis intersects the sensor at the image center.

Exercise 11 (A, 1p)
You are standing on the ground, taking a photo of a truck in front of you. You hold the camera so that the camera axis is parallel to the ground and orthogonal to the side of the truck. The height of the truck is 4 meter, which in the picture corresponds to 200 pixels, and the length of the truck is 500 pixels. How long is the truck in *meter* when the intrinsic camera parameters are represented as

$$\mathbf{A} = \begin{pmatrix} 900 & 0 & 440 \\ 0 & 1000 & 340 \\ 0 & 0 & 1 \end{pmatrix}?$$

Exercise 12 (A, 1p)
A camera with a lens or lens system often has *lens distortion*. Describe the difference between barrel and pincushion distortion. Try to draw a sketch!

Exercise 13 (A, 1p)
A general camera matrix can be written $\mathbf{C} = \mathbf{A}\,[\,\mathbf{R}\ \mathbf{t}\,]$. Zhang's calibration method allows us to estimate the intrinsic parameters in $\mathbf{A}$. This method uses a planar 2D calibration object that is shown in different orientations relative to the camera. Another way to determine $\mathbf{A}$ is to use a 3D calibration object, identify at least 6 corresponding point pairs (in 3D and in the image) and then determine $\mathbf{C}$ directly from these correspondences. What is more needed to obtain $\mathbf{A}$ from this $\mathbf{C}$?

Exercise 14 (A, 1p)
A set of images of a large scene is taken and used to produce a large panorama image. There is a geometric condition on how the images have been produced that must be satisfied in order to allow us to build a panorama image from the image set. Describe this condition, and motivate why it is necessary.

Exercise 15 (B, 2p)
The following equations are used for 3D calibration.

$$s(u,v,1)^T = \mathbf{C}\,(X,Y,Z,1)^T \tag{1}$$

$$\mathbf{C} = \begin{pmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & 1 \end{pmatrix} \tag{2}$$

$$\begin{pmatrix} X_1 & Y_1 & Z_1 & 1 & 0 & 0 & 0 & 0 & -u_1X_1 & -u_1Y_1 & -u_1Z_1 \\ 0 & 0 & 0 & 0 & X_1 & Y_1 & Z_1 & 1 & -v_1X_1 & -v_1Y_1 & -v_1Z_1 \\ X_2 & Y_2 & Z_2 & 1 & 0 & 0 & 0 & 0 & -u_2X_2 & -u_2Y_2 & -u_2Z_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & X_N & Y_N & Z_N & 1 & -v_NX_N & -v_NY_N & -v_NZ_N \end{pmatrix} \begin{pmatrix} C_{11} \\ C_{12} \\ C_{13} \\ \vdots \\ C_{33} \end{pmatrix} = \begin{pmatrix} u_1 \\ v_1 \\ u_2 \\ \vdots \\ v_N \end{pmatrix} \tag{3}$$

Describe what X_1, Y_1, Z_1, u_1 and v_1 are, and derive equation (**??**).

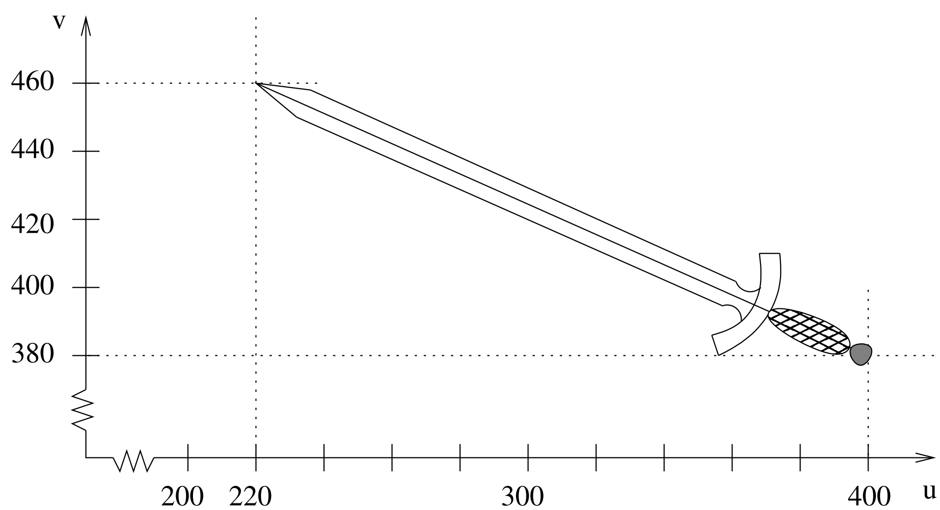
Exercise 16 (B, 2p)
A calibration matrix $\mathbf{C}$ between a planar, flat world (X,Y) measured in [dm] and the real image plane (u,v) has been established according to

$$s\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \mathbf{C}\begin{pmatrix} X \\ Y \\ 1 \end{pmatrix},$$

where

$$\mathbf{C} = \begin{pmatrix} 13 & -1.9 & 120 \\ -1.5 & 5.9 & 84 \\ 0 & -0.016 & 1 \end{pmatrix} \text{ and } \mathbf{C}^{-1} = \begin{pmatrix} 0.0769 & -0.0002 & -9.21 \\ 0.0159 & 0.138 & -13.5029 \\ 0.0003 & 0.0022 & 0.784 \end{pmatrix}.$$

A sword is placed on the plane and an image is taken, see the figure below. Determine the length of the sword in dm!



PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 (A, 1p) **Range cameras**
A range camera can be based on images of objects illuminated by a sheet-of-light laser. What type of geometric transformation describes the mapping between the laser plane (r, y) and the sensor plane (s, t)?

Exercise 18 (A, 1p) **Range cameras**
A specific scanning sheet-of-light range camera produces a 256×256 pseudo range image from 256 images of the laser profile at different sheet positions. A similar pseudo range image, of the same size and with the same content, can be obtained using structured light in the form of Gray coded patterns. How many such patterns (or images) are needed to produce this range image?

Exercise 19 (A, 1p) **3D vizualization**
The emission-absorbtion optical model that forms the physical background to the *compositing technique* for 3D volume rendering leads to the integral

$$I(D) = I_0 \exp\left[-\int_{s_0}^{D} \kappa(t)dt\right] + \int_{s_0}^{D} q(s) \exp\left[-\int_{s}^{D} \kappa(t)dt\right] ds.$$

Here, I_0 is the radiance entering the volume at $s = s_0$, and $I(D)$ is the radiance leaving the volume at $s = D$. Explain $q(s)$ and $\kappa(t)$ in this model. *Hint: it may help to draw a simple figure!*

Exercise 20 (A, 1p) **3D vizualization**
Two projection images of a 3D volume have been rendered to produce a stereo pair, as the volume will be seen by the left and right eye, respectively. What happens if you swap the images, so that the right eye sees the "left image" and the left eye the "right image"? For simplicity, you can assume that the 3D volume only contains two small objects A and B at different distance from the observer.

Exercise 21 (A, 1p) **Specialized cameras**
Compare a standard camera and an event camera in terms of how good they are at avoiding motion artifacts. Explain carefully why one is better.

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) **3D vizualization**
The program below calculates an image $S(x,z)$ with diffuse shaded surfaces based on 3D volume data $f(x,y,z)$. The camera/eye and the light source are located far away in the direction $\mathbf{V} = \mathbf{L} = (0,-1,0)$, see figure below. The volumes fx, fy and fz contain estimates of $\frac{\partial f}{\partial x}$, $\frac{\partial f}{\partial y}$ and $\frac{\partial f}{\partial z}$, respectively.

Modify the program to produce the full Phong shading with equal amount of diffuse and specular reflection. The parameter n that controls shininess can be set to 2. Ensure to treat rays reflected away from the viewer in an appropriate way.

```
for z=-127 to 128
      for x=-127 to 128
            S(x,z):=0;
            y:=-128;
            do
                  y:=y+1;
            while (f(x,y,z)<77 and y<128)
            if (f(x,y,z)<77 or fy(x,y,z)<0)
                  S(x,z):=0;
            else
                  magn := sqrt(fx(x,y,z)^2 + fy(x,y,z)^2 + fz(x,y,z)^2);
                  S(x,z):= max(fy(x,y,z) / magn, 0);
            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