Information page for written examinations at Linköping University

Examination date	2018-01-11
Room (1)	U2(30)
Time	8-12
Course code	TSBB09
Exam code	TEN2
Course name **Exam name**	Images Sensors (Bildsensorer) Written examination (Skriftlig tentamen)
Department	ISY
Number of questions in the examination	24
Teacher responsible/contact person during the exam time	Klas Nordberg
Contact number during the exam time	013-281634
Visit to the examination room approximately	around 10 am
Name and contact details to the course administrator (name + phone nr + mail)	Carina Lindström 013-284423 carina.e.lindstrom@liu.se
Equipment permitted	Calculator, pen and paper
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 one type B exercise passed (i.e., with 2 points) for the whole examination AND at least a total of 4 points each in each of the three parts.

To pass with grade 4: At least three type B exercises passed for the whole examination AND at least a total of 6 points each in each of the three parts.

To pass with grade 5: At least five type B exercises passed for the whole examination AND at least a total of 8 points each in each of the three parts.

The answers to the A-exercises should be given in the blank spaces of this examination thesis, below the questions. If an A-exercise requires two pieces of information, indicated by an"AND", both should be given to get 1p. Otherwise 0p is given.

The answers to the B-exercises should be given on blank paper sheets, with no more than one exercise per sheet, that will be appended to the thesis by the student.

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.

Good luck!
Klas Nordberg and Maria Magnusson

AID code:

PART I: STANDARD & IR IMAGE SENSORS

Exercise 1 (A, 1p) The pinhole camera model can be seen as a first order approximation of how a camera projects 3D points to a 2D image. Describe at least two effects that modify the pinhole model when the camera has a *lens*. Be specific about how each effect modifies the pinhole model.

Exercise 2 (A, 1p) Explain the concept of a *point spread function* for a camera.

Exercise 3 (A, 1p) An object is placed in room temperature $T = 20°$, and after a while the object's temperature is T. This means that it will emit radiation according to Planck's law for temperature T. The radiation corresponds to energy that leaves the object, which suggests that the object's temperature should decrease. Why does this not happen?

AID code:

Exercise 4 (A, 1p) An IR sensor measures the radiation from a surface, at some distance from the sensor, in order to determine the temperature of the surface based on the detected radiation. Describe at least two factors, specific to IR sensors, that disturb this temperature measurement.

Exercise 5 (A, 1p) Why is the optics of a IR-sensor made of rather expensive materials, such as germanium, instead of glass?

Exercise 6 (A, 1p) Explain how the measurement of light in a CMOS camera, in terms of a voltage, is transported to the circuit that converts it to a digital representation, and describe in what way this is an advantage relative to the transport mechanism used for a CCD-sensor.

Exercise 7 (B, 2p) A small part of a Bayer image is shown below, left, with a corresponding Bayer pattern, right. Compute the numerical values of *Rimage*, the resulting red (R) color plane, for the small part of the image. For simplicity, assume that pixels outside the small part of the image are zero.

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

Bayer image

G	R			
B	G			

Bayer pattern

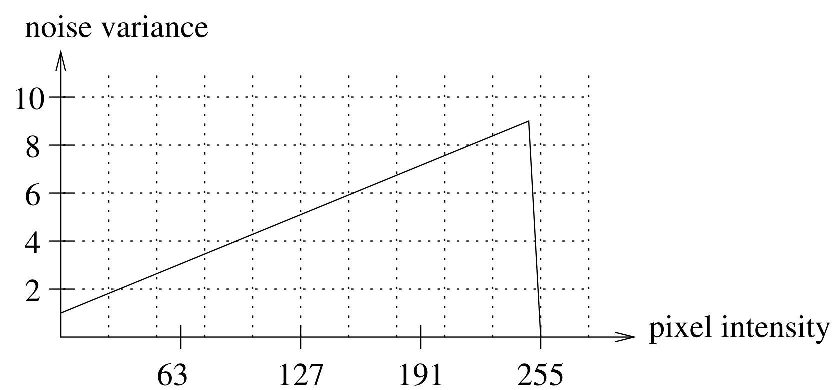
Rimage ?

Use normalized averaging with the interpolation kernel w shown below (center is marked in boldface).

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

WRITE YOUR ANSWER ON A SEPARATE SHEET

Exercise 8 (B, 2p) The figure below shows a diagram, where the noise variance is plotted against the pixel intensity for a camera sensor.



- What is the variance of the shot noise (photon noise) at the intensity 127?
- What is the total variance of other noise sources, such as dark current and thermal noise at the intensity 127?
- What is the $\text{SNR}_{\text{DB}} = 10 \log_{10}(S/N)$ at the intensity 127?
- Why does the noise variance go down to zero at intensity 255?

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PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 (A, 1p) Given two camera matrices $\mathbf{C}_1$ and $\mathbf{C}_2$, the corresponding fundamental matrix is computed as $\mathbf{F} = [\mathbf{e}_{12}]_\times \mathbf{C}_2 \mathbf{C}_1^T (\mathbf{C}_1 \mathbf{C}_1^T)^{-1}$. Explain how $\mathbf{e}_{21}$ is determined from $\mathbf{C}_1$ and $\mathbf{C}_2$, and explain why it follows that $\det \mathbf{F} = 0$ from this expression.

Exercise 10 (A, 1p) Let $\mathbf{y}_1$ and $\mathbf{y}_2$ be two points in a pair of stereo images, one in each image. Why is not meaningful to triangulate a 3D point from $\mathbf{y}_1$ and $\mathbf{y}_2$ unless the two image points satisfy (approximately) the epipolar constraint?

Exercise 11 (A, 1p) An alternative to rectification of images taken by a stereo rig is to make a mechanical adjustment of the cameras in the rig. What type of adjustment is that?

Exercise 12 (A, 1p) The intrinsic camera parameters are represented as

$$\mathbf{A} = \begin{pmatrix} \alpha & \gamma & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{pmatrix}.$$

Why is it often reasonable to assume $\alpha \approx \beta$?

Exercise 13 (A, 1p) If a panorama image is constructed from images in a large range of directions, the total image may become very warped at the edges when only homography transformations are used in the stitching process. Describe an alternative approach that works better in this case.

Exercise 14 (A, 1p) Why is it not a good idea to make a panorama image of two general stereo images?

AID code:

Exercise 15 (B, 2p) Describe an algorithm that estimates the fundamental matrix **F** from a set of N corresponding points in a pair of stereo images. Be detailed in the computational steps that are used in the algorithm. The resulting fundamental matrix must generate epipolar lines that intersect at the epipolar point in each image.

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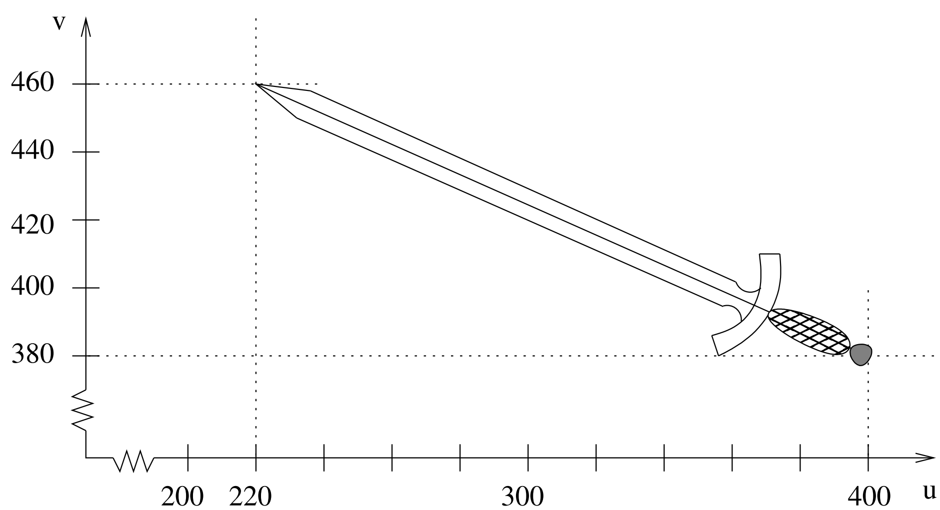
Exercise 16 (B, 2p) A calibration matrix **C** between a planar, flat, world (X, Y) measured in [dm] and the image plane with pixel coordinates (u, v) has been established according to

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

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



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PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 (A, 1p) Describe an application that makes use of a *line camera*.

Exercise 18 (A, 1p) One type of range cameras uses a time-of-flight technique, based on the phase-shift principle of modulated IR-light. Such a camera can only give correct depth estimates for a certain range interval. For example, a specific camera can work in the interval 0-7 m, or 7-14 m, or 14-21 m, but not the full range 0-21 m. Explain why, preferably with an illustration.

Exercise 19 (A, 1p) A 3D object is visualized as an image. The intensity I at a point on an object can be written

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

where $\mathbf{L}, \mathbf{N}, \mathbf{R}$ and $\mathbf{V}$ are unit vectors pointing in the direction of the light, surface normal, reflected ray and eye, respectively. However, the equation should rather be written

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

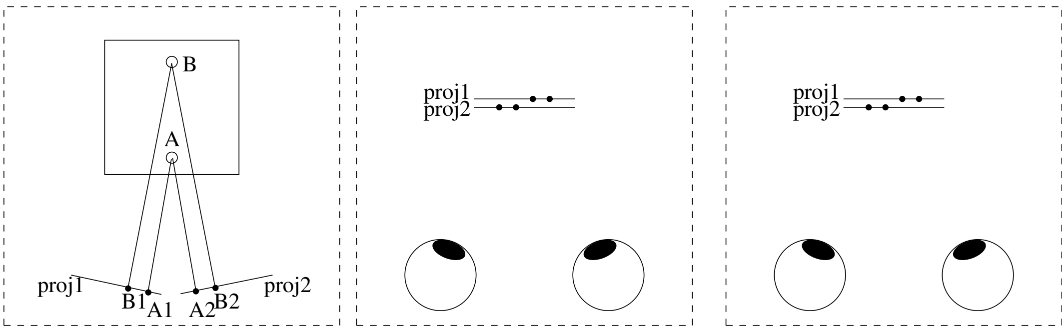
Why?

AID code:

Exercise 20 (A, 1p) Two projection images, proj1 and proj2, of a 3D volume have been rendered to produce a stereo pair, see the left figure.

- In the middle figure, draw projection lines to illustrate the correct case when the left eye sees proj1 and the right eye sees proj2.

- In the right figure, draw projection lines to illustrate the wrong case when the left eye sees proj2 and the right eye sees proj1. Consequently, what happens if we swap the images for the right and left eye?



Exercise 21 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 what $q(s)$ and $\kappa(t)$ are in this model. *Hint: it may help to draw a simple figure!*

Exercise 22 (A, 1p) (A, 1p) The reconstruction algorithm for fanbeam filtered backprojection is written below. Make small changes in the algorithm, so that it becomes Feldkamps' reconstruction algorithm instead.

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

1. Take fanbeam projections: $R_\beta(\gamma)$.

2. Perform preweighting of the projections.

3. Perform ramp-filtering.

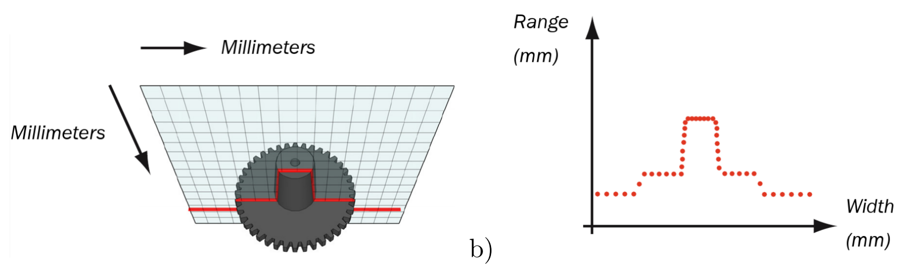
4. Perform backprojection along the fanbeam rays.

AID code:

Exercise 23 (B, 2p) The Ruler E600 is a calibrated sheet-of-light range camera. The object (see figure a) is still and the camera is moving in the x-direction while collecting data at 50 positions separated by Δx=2 mm. The camera outputs 2 matrices:

- a 45×50 matrix $\texttt{Range}(1:45, 1:50)$ consisting of range values measured in mm
- a 45×50 matrix $\texttt{Width}(1:45, 1:50)$ consisting of y-coordinates measured in mm

Figure a) illustrates the object with the laser sheet at position number 20 of the camera and figure b) illustrates the corresponding measurements, $\texttt{Range}(1:45, 20)$ and $\texttt{Width}(1:45, 20)$. (Note that 45 points are measured for each position.) The bottom of the object is located at Range=400 mm.



a) b)

Write a careful description or a simple program (e.g. matlab- or pseudo-code) that computes the volume of the object in mm^3. For simplicity, disregard occluded points.

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Exercise 24 (B, 2p) The figure below shows parallel ramp filtered projection data from 4 different directions (left). Calculate the (parallel) backprojection, using nearest neighbor interpolation for all points in the 5×5 image. The center of the image and of the projections are marked with a thick frame. The sampling distances in the image and in the projection data are equal. Present intermediate results.

ϕ=0°	0	0	−1	**3**	3	−1	0
ϕ=45°	0	0	−1	**1**	4	1	−1
ϕ=90°	0	0	−1	**3**	3	−1	0
ϕ=135°	0	−1	1	**4**	1	−1	0

rampfiltered projection data

image

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