Information page for written examinations at Linköping University

Examination date	2020-01-16
Room (2)	U7(14) U10(18)
Time	8-12
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
Visit to the examination room approximately	9.00, 11.00
Name and contact details to the course administrator (name + phone nr + mail)	Carina Lindström 013-284423 carina.e.lindstrom@liu.se
Equipment permitted	pen and paper
Other important information	Calculator is not needed!
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.

The answers to the A-exercises should be given in the blank spaces of this examination thesis, below the questions.

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.

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**
Light from two separate monochromatic sources with different wavelengths, $\lambda_1 < \lambda_2$, are measured by a light sensor. It senses the same energy per time and area unit for both sources. Does this mean that the number of detected photons per time and area unit from the first source, n_1, is the same as from the second source, n_2, or is it the case that $n_1 < n_2$ or $n_1 > n_2$? Motivate your answer.

Exercise 2 (A, 1p) **Image formation**
A pin-hole camera forces all light that enters the camera to pass through a small hole. A modern camera uses instead a lens (or a system of lenses) in combination with a larger opening for the light, the *aperture*. Describe advantages and disadvantages of these two types of camera design.

Exercise 3 (A, 1p) **Image formation**
How does *vignetting* manifest itself in an image?

Exercise 4 (A, 1p) **Image sensors**
Describe the distinct difference between an image produced by a camera using a *global shutter* versus a *rolling shutter*.

AID code:

Exercise 5 (A, 1p) **Image sensors**
A digital camera is subject to *shot-noise* (photon noise). Why does this noise occur?

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

- Ultra Violet
- Visible
- Near infrared
- Shortwave infrared
- Midwave infrared
- Longwave infrared
- Far infrared

Which two of them corresponds to thermal infrared?

Exercise 7 (B, 2p) **Image sensors**
Explain the concept of *fill factor* of an image sensor, describe factors that limit the fill factor, and describe a technique for increasing the fill factor.

WRITE YOUR ANSWER ON A SEPARATE SHEET

Exercise 8 (B, 2p) **Infrared and Multispectral Imaging**
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 *three* factors, specific to IR sensors, that disturb this temperature measurement.

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PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 (A, 1p)
Some objects in the 3D world gives a homography mapping through the lens to the camera sensor. Describe how such an object looks like!

Exercise 10 (A, 1p)
Suppose that you have taken a photo of a square located orthogonal to the optical axis of your camera. The photo shows a rectangle with the relation width/height = 1.1. What information does this number give about the intrinsic camera parameters, which are found in the matrix

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

Exercise 11 (A, 1p)
Consider the following expression, which describes the projection of a 3D point (X, Y, Z) to an image point (u, v):

$$s \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \mathbf{K}[\mathbf{R}\,\mathbf{t}] \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}, \quad \text{where} \quad \mathbf{K} = \begin{pmatrix} \alpha & \gamma & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{pmatrix}.$$

In Zhang's algorithm, a set of calibration planes are shown to the camera and corresponding homographies $\mathbf{H}$ are determined, from which $\mathbf{K}[\mathbf{R}\mathbf{t}]$ can be solved. How many calibration planes are needed at least, to determine $\mathbf{K}$? Motivate your answer!

Exercise 12 (A, 1p)
An advantage with Zhang's method for camera calibration is that it only requires a simple 2D calibration pattern.
An alternative to Zhang's method is to use a 3D calibration object and solve $\mathbf{C}$ in

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

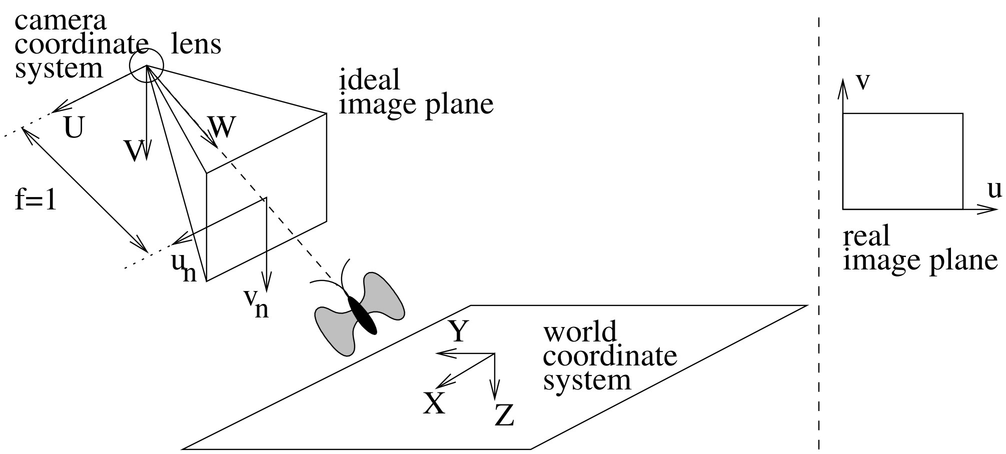
It is then possible to extract $\mathbf{A}[\mathbf{Rt}]$ from $\mathbf{C}$ if desired. What is the minimum number of 3D points on the 3D calibration object in order to solve $\mathbf{C}$?

Exercise 13 (A, 1p)
When creating a panorama in spherical coordinates, you used the solution of the *'Orthogonal Procrustes Problem'* (OPP) in the computer exercise. What is OPP used for in this particular application? Specify the input and output of this algorithm for this application.

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)
The figure below shows the 3D world, a camera, a normalized image plane (with focal length $f = 1$) and a real image plane in the camera. These are the connections between the coordinate systems, as well as the current $\mathbf{A}$-matrix:

$$s \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \mathbf{A}[\mathbf{R}\ \mathbf{t}] \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}, \qquad \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \mathbf{A} \begin{pmatrix} u_n \\ v_n \\ 1 \end{pmatrix}, \qquad \mathbf{A} = \begin{pmatrix} 500 & 0 & 500 \\ 0 & 450 & 400 \\ 0 & 0 & 1 \end{pmatrix}.$$



The camera can rotate in two angular directions θ_u and θ_v (horizontally and vertically). The image center is located at the coordinate $(u, v) = (500, 400)$. The camera should follow an object in the scene, here a butterfly. At some point in time the butterfly is located at image coordinate $(u, v) = (275, 175)$. How much should the camera rotate, in terms of the angles θ_u and θ_v, to bring the butterfly to the center of the image? The angles can be given as $\theta_u = \arctan(a)$ and $\theta_v = \arctan(b)$, where you determine a and b!

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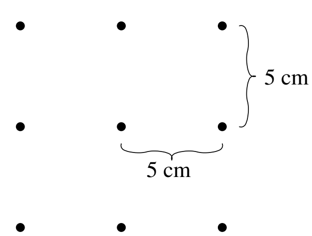
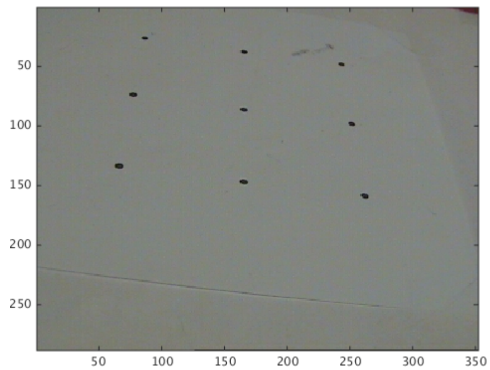
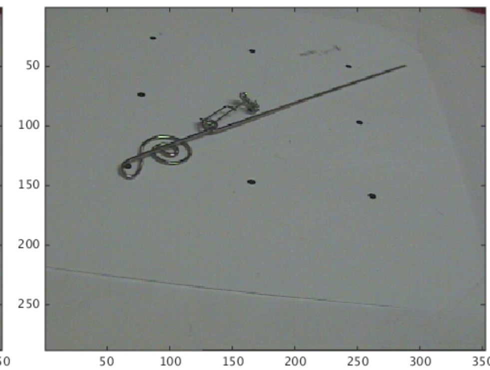
Exercise 16 (B, 2p) **Related to Computer Exercise C Camera Calibration**
The figure below shows a calibration pattern with 9 equidistant points.



Below, Fig. a) shows a camera image of the calibration pattern. The pixel coordinates of the 9 points are: (86,26), (165,37), (243,48), (77,74), (166, 86), (251,98), (66,133), (165,147), (261,159).
Fig. b) shows a camera image of an object together with the calibration pattern in the same relation to the camera as in figure a).



a) calibration image



b) object image

The following equations are used when calibrating a homography.

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

$$\mathbf{H} = \begin{pmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & 1 \end{pmatrix} \tag{2}$$

$$\begin{pmatrix} X_1 & Y_1 & 1 & 0 & 0 & 0 & -u_1X_1 & -u_1Y_1 \\ 0 & 0 & 0 & X_1 & Y_1 & 1 & -v_1X_1 & -v_1Y_1 \\ X_2 & Y_2 & 1 & 0 & 0 & 0 & -u_2X_2 & -u_2Y_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & X_N & Y_N & 1 & -v_NX_N & -v_NY_N \end{pmatrix} \begin{pmatrix} H_{11} \\ H_{12} \\ H_{13} \\ \vdots \\ H_{32} \end{pmatrix} = \begin{pmatrix} u_1 \\ v_1 \\ u_2 \\ \vdots \\ v_N \end{pmatrix} \tag{3}$$

a) Describe reasonable values for $X_1,\ Y_1,\ X_2,\ Y_2,\ X_3,\ Y_3$ and $u_1,\ v_1,\ u_2,\ v_2,\ u_3,\ v_3$ when we want to determine the homography transformation $\mathbf{H}$ between the calibration pattern and the camera image. (Different solutions are possible.)

b) Describe carefully, step by step, how to measure the length of the object in centimeters, given the three images.

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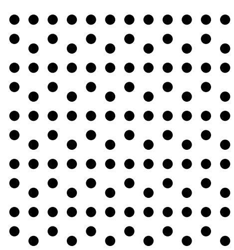
PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 (A, 1p) **Exotic cameras**
How can a light-field camera be implemeted in practice?

Exercise 18 (A, 1p) **Range cameras**
The Kinect range camera (version 1) illuminates the scene or object with a dot pattern. The following (part of a) dot pattern is not suitable for the method that Kinect uses for range computation. Explain why.



Exercise 19 (A, 1p) **Range cameras**
One principle used by time-of-flight range cameras is *Amplitude modulated light and phase shift measurement*. The Kinect range camera (version 2) uses this technique and three modulation frequencies. What is the disadvantage if only one modulation frequency is used?

Exercise 20 (A, 1p) **Range cameras**
Range sensors output 3D point sets. Point set registration is of interest. The classical ICP algoritm (not complete) works as follows .

1) Guess correspondences using current best guess of registration.
2) Estimate the *rotation* with the solution to the *'Orthogonal Procrustes Problem'* (OPP)
3) Update correspondences, and goto 2

Show how the algorithm should be supplemented so that the *translation* is also estimated.

Exercise 21 (A, 1p) **3D visualization**
The specular reflection term in Phong's formula is given by

$$I_{\text{specular}} = \text{constant} \cdot (\mathbf{R} \cdot \mathbf{V})^n$$

where $\mathbf{R}$ and $\mathbf{V}$ are unit vectors pointing in the direction of the reflected ray and the eye, respectively. What is the geometrical interpretation of $\mathbf{R} \cdot \mathbf{V}$ having a negative value? How is this case treated in 3D visualization?

Exercise 22 (A, 1p) **3D visualization**
The following equation is used in 3D-visualization. Explain the variables I, I_0, L, and μ AND explain which physical phenomena the equation is able to model.

$$I = I_0 \exp\left(-\int_L \mu(x,y)dl\right)$$

Note: The equation is also used in computed tomography (CT). Don't write about that! It is no longer included in the course.

Exercise 23 (B, 2p) **Exotic cameras**
The technique with "coded aperture" can be used to extend the depth-of-field of a camera. The equation $|f_k * x - y|^2$ is of importance. From an unsharp image y, a sharp image x, can be calculated. How? In particular, mention what f_k is, what k is, and how does f_k vary with k.

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Exercise 24 (B, 2p) **Range cameras**
Varying object reflectivity, e.g. a dark character on a white background, can introduce inaccuracies when the 3D shape of the object is being estimated using a laser sheet and triangulation.
Below are three images, a), b) and c).
The desired position of one laser point on the detector is indicated with a black point (•) in the three images. However, the real detected position is different from the desired position.
Explain and indicate the real position of the detected laser point in the three images. Also indicate the desired and the obtained position of the range, along the r-axis in figure c).