Information page for written examinations at Linköping University

Examination date	2016-01-11
Room (1)	TB
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, 0739-037628
Visit to the examination room approximately	around 10 am
Name and contact details to the course administrator (name + phone nr + mail)	
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) Explain the concept of *the radiometric chain* in the image formation process.

Exercise 2 (A, 1p) Explain the concept of *chromatic aberration* for lenses in a camera and describe how it affects the quality of the resulting image?

Exercise 3 (A, 1p) Infra-red cameras can be either with or without active cooling. Cooled cameras are more expensive, but also "better" than uncooled cameras. Describe at least one **specific quality** that makes cooled cameras better than uncooled ones.

Exercise 4 (A, 1p) A one-chip colour camera can have filters that only allow light in certain ranges to pass before it is measured by the sensor. In some cameras these ranges can be labeled as *red*, *green*, and *blue*. Alternatively, it can instead have filters referred to as *cyan*, *yellow*, *magenta*. What is the advantage of the latter set of filters compared to the first one?

AID code:

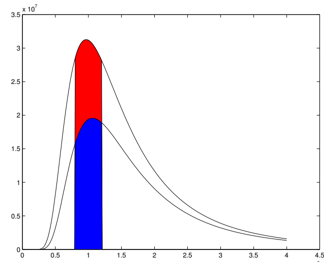
Exercise 5 (A, 1p) A pin-hole camera forces all light that enters the camera to pass through a small hole, the *aperture*. A modern camera uses instead a lens (or a system of lenses) in combination with a larger opening for the light. Describe advantages and disadvantages of these two types of camera design.

Exercise 6 (A, 1p) A CCD-sensor converts light into electrical charges that are accumulated under a MOS-transistor. Why does the electric charge stay under the transistor instead of spreading out into the semiconductor material and neighboring pixels?

Exercise 7 (B, 2p) The digital readout value from a sensor pixel has no obvious physical unit of measurement. On the other hand, the image sensor has a number of internal physical parameters that affect the pixel value. Describe at least two internal physical parameters which the digital pixel value is proportional to, and explain why.

WRITE YOUR ANSWER ON A SEPARATE SHEET

Exercise 8 (B, 2p) In the computer exercise related to infra-red sensors you were acquainted with functions that are plotted in the figure below. What functions are illustrated here, what physical entities are on the horizontal and vertical axes? What is the physical difference between the two curves? What does the red and blue areas represent in relation to the infra-red sensor? (Note: the red area goes all the way down to the horizontal axis)



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PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 (A, 1p) The *fundamental matrix* **F** defines a matching constraint between points in stereo images, called the *epipolar constraint*. How is this constraint formulated? Describe the additional variables that occur in the constraint.

Exercise 10 (A, 1p) Rectification of two stereo images corresponds to a virtual adjustment of the principal axes of the two cameras in a specific way. In what way?

Exercise 11 (A, 1p) Panorama images based on image stitching or image mosaics use a set of images of a 3D scene that are produced in a particular way. Describe a critical assumption about how the images are produced, i.e., how the cameras are configured, which is used when forming the panorama image in this way.

Exercise 12 (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.

AID code:

Exercise 13 (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 14 (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, $\mathbf{H} = \mathbf{K}[\mathbf{R}\mathbf{t}]$. How many calibration planes are needed at least, to determine $\mathbf{K}$? Motivate your answer!

Exercise 15 (B, 2p) The epipolar constraint is not just a theoretical result. It has also practical applications. Describe such an application.

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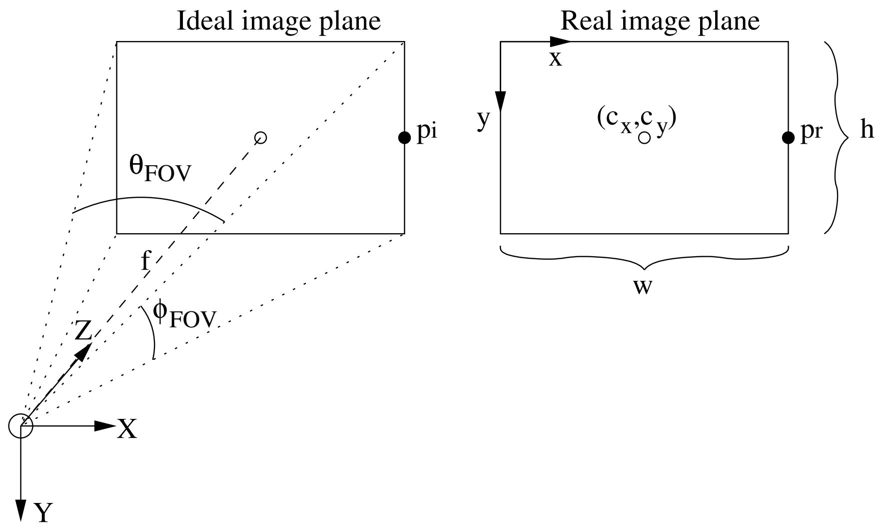
Exercise 16 (B, 2p) When using panorama stitching in spherical coordinates, the horizontal and vertical fields of view, θ_{FOV} and ϕ_{FOV}, are determined. See the figure below, which describes the geometry inside the camera with the camera coordinate system (X, Y, Z) and the ideal image plane. The real image plane, which is measured in pixels, is shown to the right. Its width and height, w and h, are indicated in the figure.



The camera calibration matrix (which gives the intrinsic camera parameters) can be written as:

$$\mathbf{K} = \begin{pmatrix} kf & \gamma & c_x \\ 0 & f & c_y \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} \alpha & 0 & c_x \\ 0 & \beta & c_y \\ 0 & 0 & 1 \end{pmatrix} . \tag{1}$$

Compute the horizontal and vertical fields of view θ_{FOV}, and ϕ_{FOV} in terms of simple expressions that includes w, h, α and β.

Notes and hints:

- In reality, the position of the real image plane is, of course, behind the lens.
- We have often used the notation (u, v) instead of (x, y) in the course.
- We have assumed $\gamma = 0$, which is also seen in the figure.
- It might be helpful to start by setting up the relation between the points p_i and p_r.

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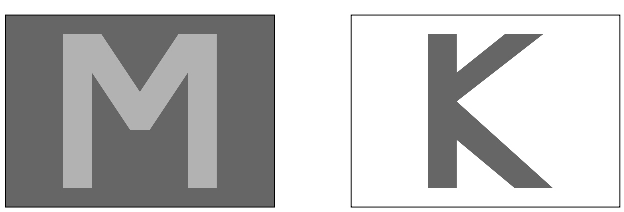
PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 (A, 1p) To achieve a high dynamic range image in a CMOS camera, the photo diodes of the sensor are first precharged with 50% of their maximum bias voltage and exposed during time $2\,T$. Then they are precharged again with the remaining 50% bias voltage, and exposed during time T. Draw the curve that describes how the resulting voltage V over a specific diode depends on the intensity I falling on the diode. **Be specific about the slopes of this curve!**

Exercise 18 (A, 1p) One type of range camera is based on laser sheet-of-light and triangulation. Which object may give problems, an object with a diffuse reflecting surface or an object with a specular reflecting surface? Motivate your answer!

Exercise 19 (A, 1p) Two printed cards with flat surfaces, one with an “M” and one with a “K” are shown below. They are scanned with a range camera based on sheet-of-light and triangulation. Although the surfaces are flat, the resulting range images are not flat. One of the cards contains larger deviations from a flat surface than the other. Explain why!



AID code:

Exercise 20 (A, 1p) One type of range camera is based on gray coded patterns and triangulation. Suppose that a resolution of 512×512 in the range image is desired. How many gray coded patterns is needed? Motivate your answer!

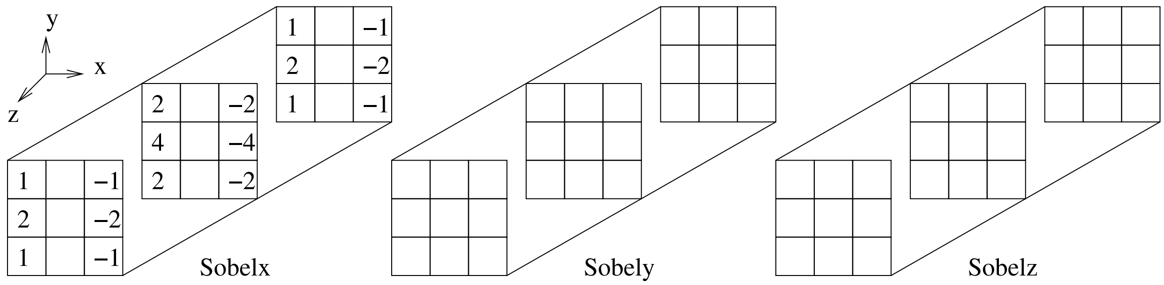
Exercise 21 (A, 1p) Suppose that we have sinogram projection data of size $[N_\phi, N_r]$, i.e. N_ϕ projection angles and N_r detector elements. Suppose that the image size after reconstruction is $N \times N$, where $N_r = N$.
The following relation is valid: $N_\phi = (\pi/2) \cdot N_r$.
Vad happens with the image quality if we reduce the number of projection angles to $N_\phi = (\pi/4) \cdot N_r$? Choose among:

- much better
- slightly better
- slightly worse, streaks are beginning to show up
- much worse, streaks are considerably destroying the image
- slightly worse, the image is slightly blurred
- much worse, the image is very blurred

Exercise 22 (A, 1p) MIP (Maximum Intensity Projection) is used in 3D visualization. Describe how a MIP is generated.

AID code:

Exercise 23 (B, 2p) Surface shading is often used for 3D visualization of 3D volumes. It relies on surface normal calculations. The 3D sobel filters can be used for estimation of the 3D derivatives in a volume, $\frac{\partial f(x,y,z)}{\partial x}$, $\frac{\partial f(x,y,z)}{\partial y}$, $\frac{\partial f(x,y,z)}{\partial z}$. Sobelx is shown below. Give Sobely and Sobelz! Also give equations how to calculate the unit surface normal $\bar{n}(x,y,z)$ in one voxel using the sobel filters.



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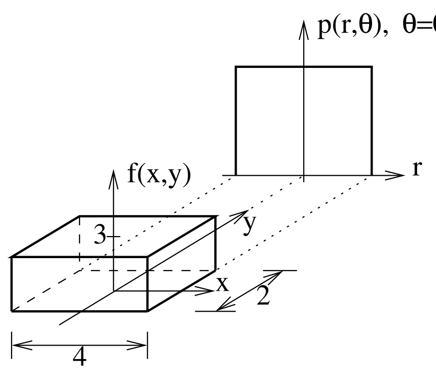
Exercise 24 (B, 2p) The figure below shows the absorption $f(x,y)$ in a 2D slice of some tissue in a CT scanner, together with its CT-projection $p(r,\theta)$, for $\theta = 0$. In this particular case: $f(x,y) = 3 \cdot \Pi(x/4) \cdot \Pi(y/2)$.



a) Determine the 2D Fourier transform $F(u,v)$ of $f(x,y)$, determine the projection $p(r,0)$ and determine its Fourier transform $P(R,0)$.
b) Show that the Projection theorem $P(R,\theta) = F(R\cos\theta, R\sin\theta) = F(u,v)$ is valid for $\theta = 0$. Use the Fourier transform table below.

	Spatial domain	**Fourier domain**
1D:	$f(x)$	$F(u)$
Scaling:	$f(ax)$	$(1/\|a\|) \cdot F(u/a)$
Rectangle:	$\Pi(x)$	$\text{sinc}(u)$
2D:	$f(x,y)$	$F(u,v)$
Scaling:	$f(ax,by)$	$(1/\|ab\|) \cdot F(u/a, v/b)$
Box:	$\Pi(x) \cdot \Pi(y)$	$\text{sinc}(u) \cdot \text{sinc}(v)$

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