Försättsblad till skriftlig tentamen vid Linköpings universitet

Datum för tentamen	2018-04-03
Sal (1)	TER4(9)
Tid	14-18
Kurskod	TSBB09
Provkod	TEN2
Kursnamn/benämning **Provnamn/benämning**	Bildsensorer Skriftlig tentamen
Institution	ISY
Antal uppgifter som ingår i tentamen	24
Jour/Kursansvarig Ange vem som besöker salen	Klas Nordberg
Telefon under skrivtiden	013-281634
Besöker salen ca klockan	around 4 pm
Kursadministratör/kontaktperson (namn + tfnr + mailaddress)	Carina Lindström 013-284423 carina.e.lindstrom@liu.se
Tillåtna hjälpmedel	Calculator, pen and paper
Övrigt	
Antal exemplar i påsen	

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

PART I: STANDARD & IR IMAGE SENSORS

Exercise 1 (A, 1p) Explain the meaning of the *plenoptic function*, as a function of position $\mathbf{x} = (x_1, x_2, x_3)$ and direction $\hat{\mathbf{n}} = (n_1, n_2, n_3)$ in 3D space ($\hat{\mathbf{n}}$ is a normalized vector).

Exercise 2 (A, 1p) Explain the meaning of the *object plane* for a lens based camera.

Exercise 3 (A, 1p) Not every photon that falls onto a detector element in a sensor chip is converted into an electron/hole pair that contributes to the measured intensity. Give at least two examples of how a photon can fail to generate an electron/hole pair.

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Exercise 4 (A, 1p) A simple infra-red sensor can often have significant levels of *fixed pattern noise* (non-uniformity). Explain what this is.

Exercise 5 (A, 1p) Explain how a *multi-spectral camera* is related to a *push-broom sensor*.

Exercise 6 (A, 1p) The electromagnetic radiation emitted from an object is distinctly different if the object is cold or warm. Describe the qualitative difference of this radiation for the two cases, for examples in terms of a figure that shows how the radiated energy depends on both temperature and on the wavelength/frequency of the light.

Exercise 7 (B, 2p) The resolution of the camera, i.e., the smallest detail that can be resolved, is limited. One limiting factor has to do with the optical system that projects the image to the image plane. Explain this factor (1p). Another factor has to do with the number of detector elements (pixels) per millimeter in the sensor chip. Explain how this second factor should be related to the first one (1p).

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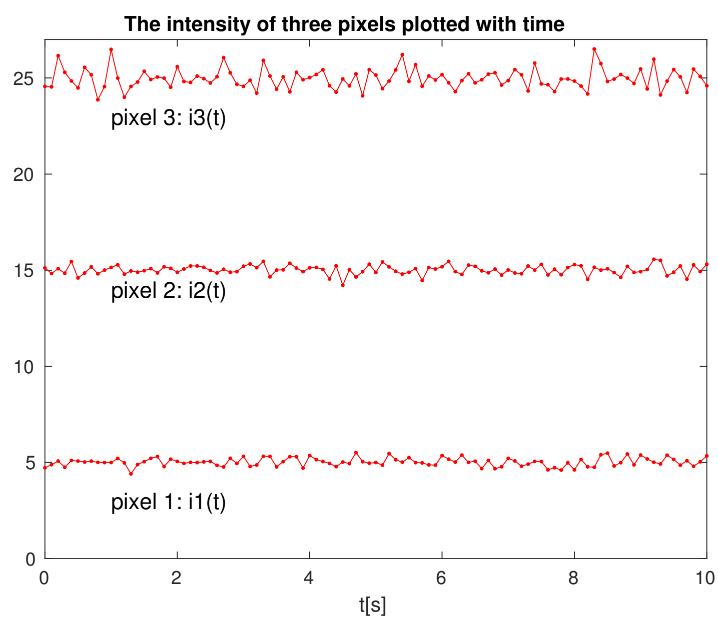
Exercise 8 (B, 2p) The figure below shows a diagram, where the intensity for three pixels in a camera sensor, $(i1(t), i2(t), i3(t))$, are measured for 101 time instances. With this data, the variances of the pixel intensities are estimated as $\mathrm{var}(i1) \approx 0.05$, $\mathrm{var}(i2) \approx 0.05$ 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.

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PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 (A, 1p) What is the geometric interpretation of the *epipolar points* corresponding to a pair of stereo cameras?

Exercise 10 (A, 1p) The two images produced by a stereo rig should be rectified. This is done by applying a rectifying homography transformation $\mathbf{H}_1$ and $\mathbf{H}_2$ onto the respective image. What is the defining algebraic relation for $\mathbf{H}_1$ and $\mathbf{H}_2$ to make them rectifying homographies? Which additional matrix appears in this relation?

Exercise 11 (A, 1p) A 3D point with homogeneous coordinates $\mathbf{x}$ is mapped through two known camera matrices, $\mathbf{C}_1$ and $\mathbf{C}_2$, to two image points: $\mathbf{y}_1 \sim \mathbf{C}_1\mathbf{x}$ and $\mathbf{y}_2 \sim \mathbf{C}_2\mathbf{x}$. Given that the image points $\mathbf{y}_1, \mathbf{y}_2$ are known, describe an algebraic method that determines an estimate of $\mathbf{x}$.

Exercise 12 (A, 1p) Camera calibration may include also to determine the lens distortion. The simplest form of lens distortion is *radial distortion*. Explain what this is.

Exercise 13 (A, 1p) In the panorama laboratory exercise, two images are taken with the same camera, with only a rotation $\mathbf{R}$ around the camera center between the images, and without changing the internal camera calibration matrix $\mathbf{K}$. The two images differ only by a geometric transformation in terms of a homography $\mathbf{H}$. How is $\mathbf{H}$ related to $\mathbf{K}$ and $\mathbf{R}$?

Exercise 14 (A, 1p) Zhang's method for camera calibration is based on the expression

$$\lambda \, \mathbf{A} \, [\, \mathbf{r}_1 \; \mathbf{r}_2 \; \mathbf{t} \,] = [\, \mathbf{h}_1 \; \mathbf{h}_2 \; \mathbf{h}_3 \,] ,$$

where $[\, \mathbf{h}_1 \; \mathbf{h}_2 \; \mathbf{h}_3 \,]$ is the measured homography for one view of the calibration pattern. This expression allows us to formulate two constraints on $\mathbf{A}$, where one constraint is derived from the relation $||\mathbf{r}_1|| = ||\mathbf{r}_2|| = 1$. Which is the other relation that leads to a constraint on $\mathbf{A}$?

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Exercise 15 (B, 2p) The internal parameters of a camera can be represented as an upper triangular matrix:

$$\mathbf{K} = \begin{pmatrix} \kappa_{11} & \kappa_{12} & \kappa_{13} \\ 0 & \kappa_{22} & \kappa_{23} \\ 0 & 0 & 1 \end{pmatrix}$$

Give a geometric interpretation of all five parameters κ_{ij} in this matrix.

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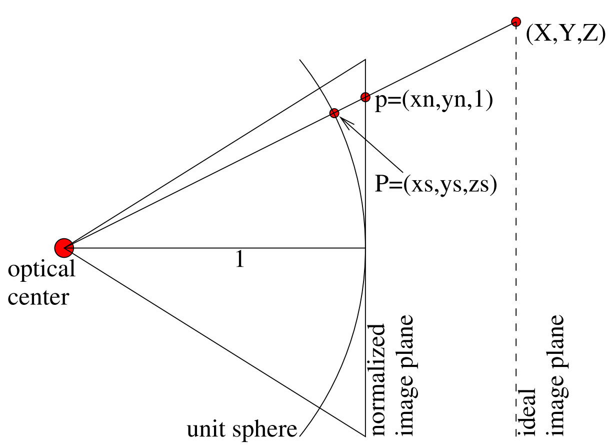
Exercise 16 (B, 2p) For panorama stitching in spherical coordinates, image points are transformed to a unit sphere and the rotation between two images is found by using Procrustes algorithm.

A point (X, Y, Z) on the ideal image plane is transformed to a point (x, y) on the real image grid through the camera matrix $\mathbf{K}$ according to

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \sim \begin{pmatrix} xZ \\ yZ \\ Z \end{pmatrix} = \mathbf{K} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} .$$

The point (X, Y, Z) on the ideal image plane corresponds to a point on the unit sphere (x_s, y_s, z_s), see the figure below.



Give equations how to calculate a point on the unit sphere (x_s, y_s, z_s) from an image grid point (x, y).

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AID code:

PART III: NON-STANDARD IMAGE SENSORS

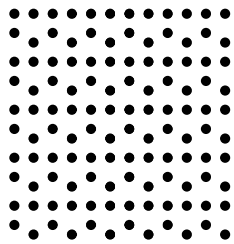
Exercise 17 (A, 1p) Describe an approach for implementing an *omnidirectional* camera.

Exercise 18 (A, 1p) When we are using a range camera with a laser line, the position of the laser line can be determined as the pixel position of maximum intensity value along each sensor row. Describe a method that increases the position accuracy of the laser line?

Exercise 19 (A, 1p) 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)?

AID code:

Exercise 20 (A, 1p) 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 21 (A, 1p) 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) The following equations is used in computed tomography (CT):

$$I(r,\theta) = I_0 \exp\left(-\int_L \mu(x,y)dl\right), \qquad p(r,\theta) = \ln\left(\frac{I_0}{I(r,\theta)}\right).$$

Which of the parameter or functions $I(r,\theta), I_0, p(r,\theta), \mu(x,y)$ are either measured or known by the CT-scanner and which are computed by the reconstruction algorithm as the output from the CT-scanner?

Exercise 23 (B, 2p) A 3D volume, e.g., in terms of X-ray absorption, has values given by $f(x,y,z)$. A certain point (x_0, y_0, z_0) in the volume has been classified as belonging to a surface that only reflects light in a diffuse way from a light source at coordinate (s_x, s_y, s_z). How much light is reflected from this point? What additional information do you need to fully solve the task?

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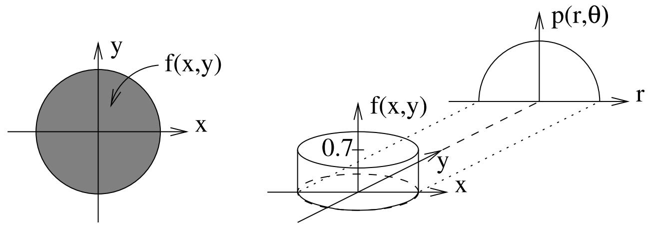
Exercise 24 (B, 2p)

a) The function $f(x, y)$ is given by

$$f(x, y) = \begin{cases} 0.7, & x^2 + y^2 \leq 1, \\ 0, & \text{otherwise,} \end{cases}$$

and it is illustrated as an image as well as with a 3D sketch below.



First compute an analytic expression of its projection data for $\theta = 0$,

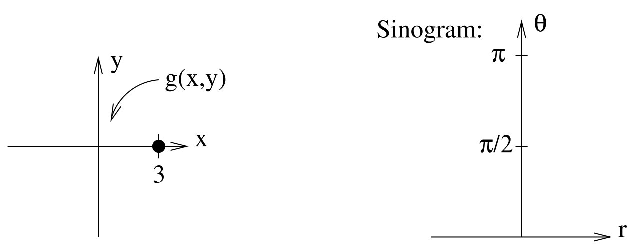
$$p(r, 0) = p(x, 0) = \int_{-\infty}^{\infty} f(x, y)\, dy.$$

Then compute its full projection data $p(r, \theta)$, i.e., the sinogram or Radon transform.

b) Consider the function $g(x, y)$ given by

$$g(x, y) = \begin{cases} 1, & (x - 3)^2 + y^2 \leq 0.01, \\ 0, & \text{otherwise,} \end{cases}$$

and illustrated as an image below. Draw its sinogram as an image in the (r, θ)-plane to the right.



Insert a marker that specifies the scale on the r-axis in the sinogram!

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