Försättsblad till skriftlig tentamen vid Linköpings universitet

Datum för tentamen	2017-01-09
Sal (1)	T2(24)
Tid	8-12
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, 0739-037628
Besöker salen ca klockan	around 10 am
Kursadministratör/kontaktperson (namn + tfnr + mailaddress)	
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

AID code:

PART I: STANDARD & IR IMAGE SENSORS

Exercise 1 (A, 1p) When light interacts with matter there are (in the basic case) only three possible outcomes. Which three?

Exercise 2 (A, 1p) Explain the concept of *depth of field* relative to a certain resolution Δx in the image plane.

Exercise 3 (A, 1p) The basic idea of using infra-red sensors is that they are able to measure properties related to the temperature of the object or objects that are in the camera view. This ideal assumption is usually correct, but not always. Give at least one example of an effect that makes the sensor readout deviate from the ideal situation, and which has nothing to do with noise in the sensor electronics.

Exercise 4 (A, 1p) Describe the concept of a *Bayer-pattern* in a digital camera. What is it used for and how?

AID code:

Exercise 5 (A, 1p) **Related to Computer Exercise A The Digital Camera**
100 images are taken from a static scene. The dominating source of noise is photon noise, which has a Poisson distribution. The average of these 100 images, `imaver`, is shown to the left and the variance of these 100 images, `imvar`, is shown to the right. What is the expected relation between the two images?

`imaver`

`imvar`

Exercise 6 (A, 1p) **Related to Computer Exercise A The Digital Camera**
See the previous exercise. Normally the two images are dark at the same places and bright at the same places. However, there are a few positions where `imvar` is dark while `imaver` is bright. Examples of this phenomena are seen at three patches in the ceiling and one patch on the floor in the bottom of the images. What is the reason for this reverse behavior?

Exercise 7 (B, 2p) A multi-spectral image is a 2D image where, at each image point, it has measurements of the light within multiple wavelength bands (typically more than the three bands in a color camera). This can be accomplished using a single broad-band sensor in combination with a filter wheel, or with optics that split light that enters the camera through a slit into a spectrum. Describe and explain the advantages and disadvantages of using the two approaches.

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Exercise 8 (B, 2p) The pin-hole camera model cannot be implemented in most practical cases, and instead it is replaced by a lens based camera. Why? Describe at least two different types of deviations from the pinhole camera model that is caused by the use of lenses, and how they affect the image formation.

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PART II: GEOMETRY AND MULTIPLE VIEWS

Exercise 9 (A, 1p) Why is it correct to say that the fundamental matrix $\mathbf{F}$, which is a 3×3 matrix, has 7 degrees of freedom (rather than $3 \times 3 = 9$)?

Exercise 10 (A, 1p) We want to triangulate a 3D point from its projections onto a stereo image pair. This is done by determining the intersection of the two projection lines. Describe how we can determine if the two lines really intersect?

Exercise 11 (A, 1p) The expression below describes the projection of a 3D point (X, Y, Z) to an image point (u, v), based on the pin-hole camera model. Describe which parameters in this expression are called *outer parameters* or *external parameters* of the camera, AND explain why.

$$s \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \mathbf{A}[\mathbf{R}\,\mathbf{t}] \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

Exercise 12 (A, 1p) A camera with image size 1000×600 pixels has the following camera calibration matrix,

$$\mathbf{A} = \begin{pmatrix} 500 & 0 & 499.5 \\ 0 & 490 & 299.5 \\ 0 & 0 & 1 \end{pmatrix}.$$

What is $\mathbf{A}$ if the camera zooms in with a factor of 3? Assume that the optical axis intersects the sensor at the image center.

Exercise 13 (A, 1p) In the complete camera calibration method of Zhang, the following equations are used for something. What?

$$\begin{cases} \breve{u} = u + (u - u_0)(k_1(x^2 + y^2) + k_2(x^2 + y^2)^2) \\ \breve{v} = v + (v - v_0)(k_1(x^2 + y^2) + k_2(x^2 + y^2)^2) \end{cases}$$

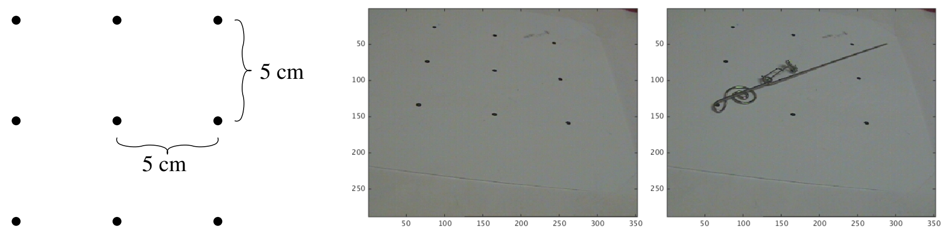
Exercise 14 (A, 1p) **Related to Computer Exercise E Panorama Images**
Two images are taken with different rotations $\mathbf{R}_1$ and $\mathbf{R}_2$, but the same camera center. In the computer exercise, the images were stitched in a spherical coordinate system, using the Matlab function `image_resample_sphere`. In order to transform image points onto the sphere, this function needs a set of parameters that describe the geometry of the problem, including the following 5 sets of parameters:

- The image to be transformed
- A rotation matrix.
- The range of horizontal angle in radians
- The range of vertical angle in radians
- The step size in radians

In addition, this function needs a sixth set of parameters to fully define the transformation. What set of parameters is this?

AID code:

Exercise 15 (B, 2p) **Related to Computer Exercise C Camera Calibration**
Fig. a) shows a calibration pattern with 9 equidistant points.
Fig. b) 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. c) shows a camera image of an object together with the calibration pattern in the same relation to the camera as in figure b).



a) pattern *b) calibration image* *c) 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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Exercise 16 (B, 2p) In the 8-point algorithm for estimation of the fundamental matrix $\mathbf{F}$ it is important to enforce the constraint $\det \mathbf{F} = 0$. Describe what can happen to the epipolar lines and epipolar points if this constraint is not satisfied. Motivate your answer.

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PART III: NON-STANDARD IMAGE SENSORS

Exercise 17 (A, 1p) The relation between the light intensity I that falls onto a pixel and the corresponding digital value D that is produced by the same pixel can in the simplest case be described as

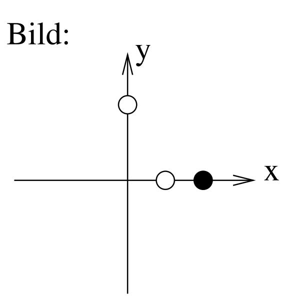
$$D = g \cdot I.$$

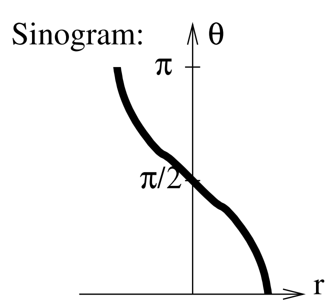
Here g is a gain factor that is constant over all pixels in the image.

So-called HDR images (High Dynamic Range) can be produced by combing two or more images of the same scene where g somehow varies between the images. Describe at least one way to accomplish this variation using a single 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) The image (left) contains a black dot and we can see how it is mapped into the sinogram (right). There are also two white points indicated in the image. Complete the sinogram with the contribution from BOTH of the white points.



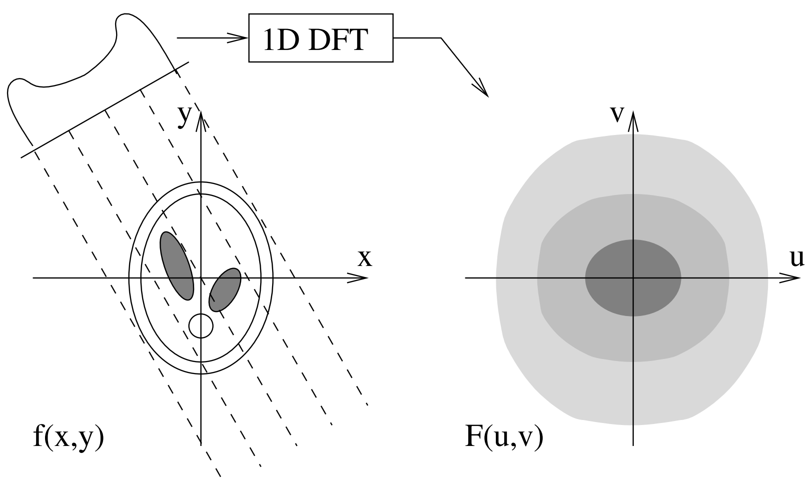


Exercise 20 (A, 1p) There exist several algorithms for "3D tomography with helix-shaped source path". Some of them give more and more artifacts (errors) when the pitch of the helix increase.
It is stated that:
"For an approximate (CT) algorithm there will always be image artifacts (errors) even though the resolution and SNR are increased unlimitedly."
Examples of 3D helical filtered backprojection algorithms are

- The PI-method developed at LiU
- WFBP (weighted filtered backprojection) from Siemens
- Katsevich's algoritm

For each of the three methods, indicate whether it is an exact or an approximate method.

Exercise 21 (A, 1p) The figure below illustrates the projection theorem, showing an object $f(x, y)$ and its two-dimensional Fourier transform $F(u, v)$. A projection and a 1D DFT are indicated. Mark the position of the Fourier transformed projection in $F(u, v)$.



Exercise 22 (A, 1p) The Blinn-Phong illumination model defines the intensity I at a point on an object as

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

$\mathbf{L}, \mathbf{N}, \mathbf{R}$ and $\mathbf{V}$ are unit vectors pointing in the direction of the light, the surface normal, the reflected ray, and the eye, respectively. What happens if n is varied?

Exercise 23 (B, 2p) The program below calculates an image $S(x,z)$ with diffuse shaded surfaces based on 3D volume data $f(x,y,z)$. The camera and the light source are located far away in the direction $\bar{s} = (0,-1,0)$. The volumes sx, sy and sz 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 one depth coded image $D(x,z)$ and one MIP (maximum intensity projection) image $M(x,z)$ of this data.

```
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 sy(x,y,z)<0)
      S(x,z):=0;
    else
      S(x,z):= sy(x,y,z) / sqrt(sx(x,y,z)^2 + sy(x,y,z)^2 + sz(x,y,z)^2);
    end
  end
end
```

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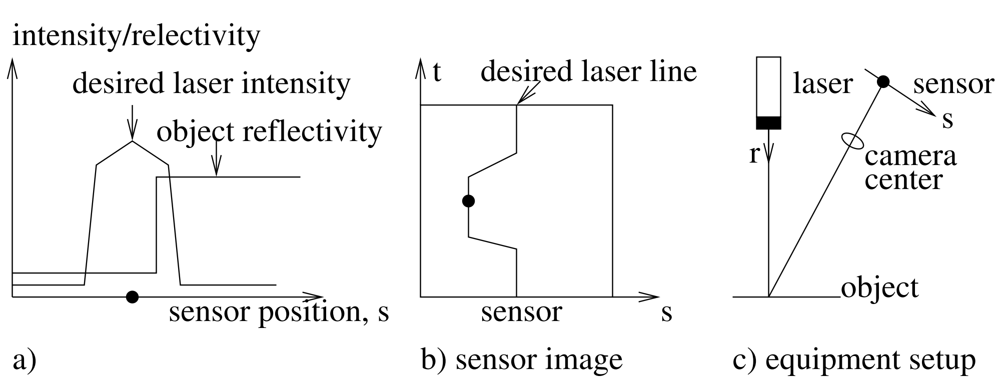
Exercise 24 (B, 2p) Varying object reflectivity, e.g. a dark character on a white background, can introduce inaccuracies when the 3D shape of the object is being estimated using a laser sheet and triangulation.
Below are three images, a), b) and c).
The desired position of one laser point on the detector 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).



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