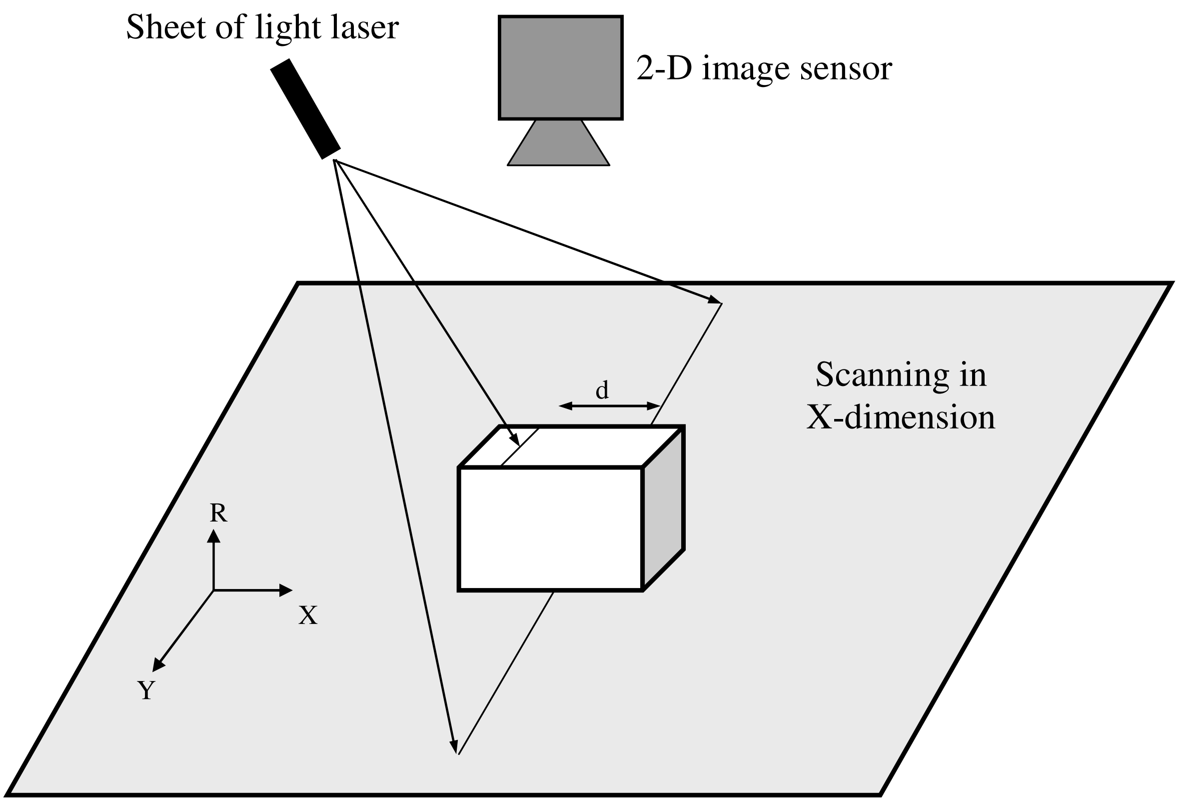
Mittuniversitetet
MID SWEDEN UNIVERSITY

Laboratory Experiments On Machine Vision



Outline

1. Optical Systems and Camera Calibration

1.1. Introduction

Before doing these experiments it is highly recommended to read chapter 2 and section 3.2.2 in textbook [1]. Lectures 2 and 3 are available on-line as video presentations [2].

Figure 1 shows a sine waveform corresponding to the grayscale intensity along one spatial dimension of an image. Contrast C for a waveform in an image is defined as $C = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$.

If this contrast value is computed for a whole range of frequencies, one at a time, we can display the contrast transfer function. This function is a measure of how good the optical system can transfer oscillations of different frequencies.

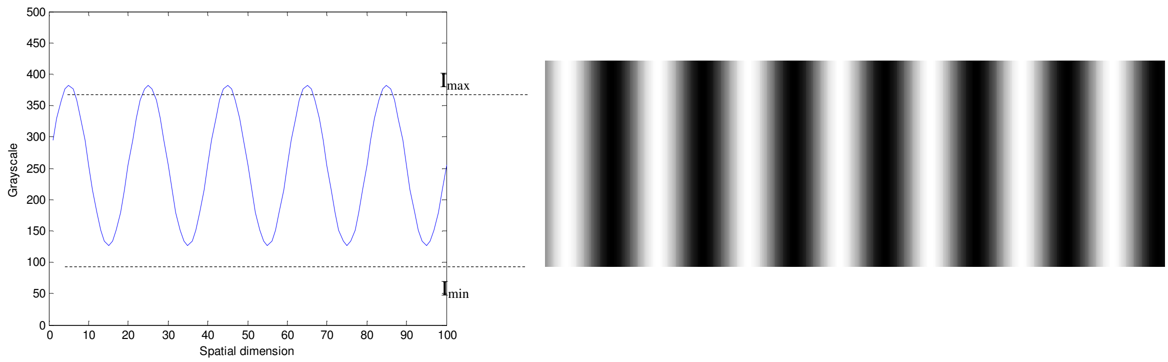


Figure 1. Sine waveform for grayscale in image.

1.2. Experimental setup

You will analyse experimental data from the image acquisition system shown in Figure 2. The goal is for you to enhance your understanding for some fundamental properties related to camera and optics.

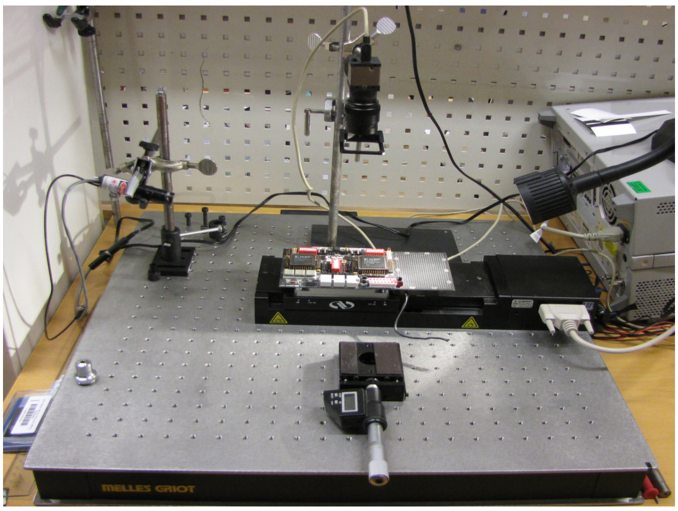


Figure 2. Image acquisition system.

We will firstly focus on the following list of properties:

- **Field Of View (FOV)** is the viewed area on object side
- **Working Distance (WD)** is the distance from object to lens
- **Depth of Field (DOF)** is the maximum depth of an object to be all in focus
- **Resolution** is the smallest resolvable feature of an object
- **Linearity** is a measure of linearity of the camera response to linear grayscale

1.3. Imaging system specification

The following data applies for the image acquisition system shown in Figure 2 that has been used to capture provided images.

- Focal length: 25 mm
- Diameter of aperture opening: 5 , 1 mm
- Working distance to test object : 130 mm, 270 mm
- Used monochrome CCD camera : uEye2250 M
    - Number of pixels: 1600 x 1200
    - Pixel size: 4.4 x 4.4 um

1.4. Summary of provided images

- L1S1T11.jpg: Picture of a test object for measuring resolution. Distance from lens to object is 130 mm.
- L1S1T12.jpg: Same as L1S1T11 but picture is made at 270 mm distance.
- L1S2T1.jpg: Picture of a test object used to measure linearity of camera.

1.5. List of useful Matlab commands

The following list of commands for Matlab is a hint on how to solve listed tasks.

- imread
- imshow
- rgb2gray
- imhist
- fft
- fftshift
- abs
- help
- lookfor

1.6. List of tasks

Task 1.

Use image files 'L1S1T11.jpg' and 'L1S1T12.jpg' and given imaging system data.

- *Find magnification of optical system. Compute magnification by applying lens formula as well as measuring amplification directly in image.*
- *Plot and Analyze spatial contrast transfer functions for the optical systems used. Maximum and minimum of the graylevel waveforms I_{max} and I_{min} are used to compute contrast C using formula* $C = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$
- *Find frequency range which causes distortion artifacts known as aliasing. Compute FFT transforms of each frequency on that test object and explain what happens at aliasing.*
- *How to avoid aliasing distortions during image acquisition?*

Task 2.

- *What is the highest spatial resolution that can be attained on <u>object side</u> for each of the experimental setups having different optical magnifications?*
- *What is the highest spatial resolution that can be attained on <u>focal plane array</u> (detector surface) for each of the experimental setups having different optical magnifications?*
- *How do you think that defocusing can affect the spatial resolution and in particular amplitude characteristic of MTF?*

Task 3.

- *Find out depth of focus for the two different optical SETUPs used in these experiments ?*
- *How the depth of focus (DOF) depends on the F-number?*

Task 4.

- *Analyze the test image 'L1S2T1.jpg' for non linear response.*
- *Build and analyze corresponding histogram .*
- *Create gray scale transformation function for the correction of non linearity.*
- *Apply this function to the test image and analyze it again.*

2. Illumination

2.1. Introduction to polarized light

Most light sources normally generate light having equal probability for all possible polarizations. Linear polarization of light or partly linear polarization appears when the waveform has only one possible orientation along its direction of propagation. This can happen when light is reflected (specular or diffused) in smooth dielectric or metallic surfaces or as in Figure 3 where light is passing a polarization filter. It is possible to exploit the polarization property of light in order to suppress specular reflections. More on this topic can be read in text book [1] in section 2.1.3 and 2.1.4.

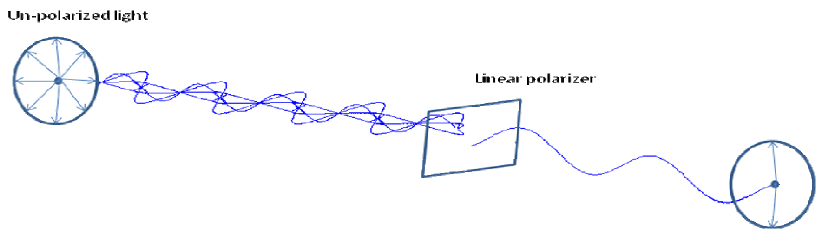


Figure 3. Linear polarization of light using polarization filter

2.2. Summary of provided images

- L2S11.jpg: Picture of circuit board using analyser in front of camera lens.
- L2S12.jpg: Picture of circuit board using polarizer in front of light source and analyser in front of camera lens.

2.3. Experimental setup for using polarized light

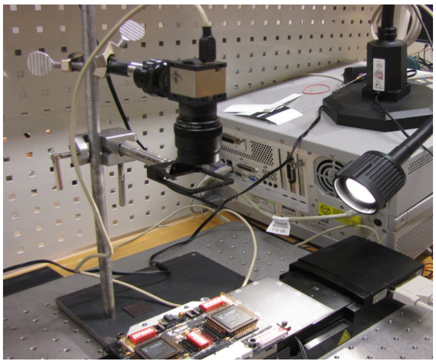


Figure 4. Setup for imaging of circuit board.

Un-polarized directed light generated by a halogen lamp is illuminating a circuit board. A camera is used to image circuit board from the top at an orthogonal projection. L2S11.jpg is captured using an analyser (polarization filter) in front of camera lens while illumination is un-polarized. L2S12 is captured using both analyser in front of camera and polarization filter in front of halogen lamp.

2.4. List of tasks

Task 1

- *Find out what parts of the image of the circuit board were emphasized and why?*
- *Calculate SNR in those parts of the images for both cases?*

2.5. Experimental setup for back-light versus front-light illumination

Figure 5 depicts the principle for an experimental setup used to image a printed circuit board having an array of through holes and using diffused back-light illumination, see image file L2S2T21.jpg. A diffuser is used to distribute over a larger area the light generated by a point source. Figure 6 shows imaging of the same circuit board using front-light illumination, see image file L2S2T22.jpg.

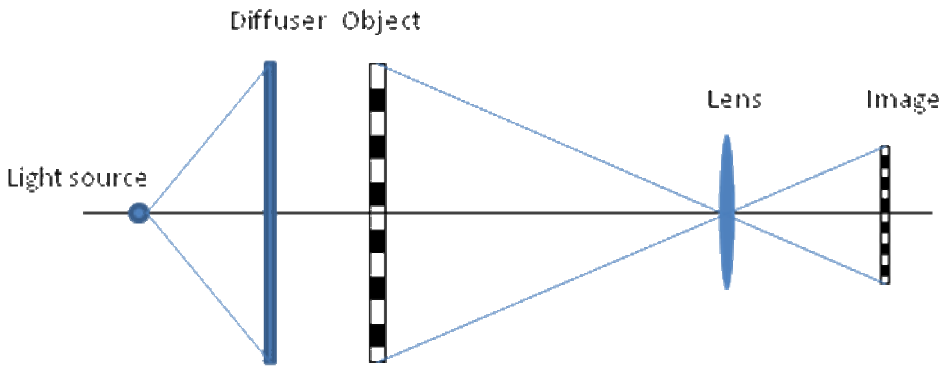


Figure 5. Experimental setup for back-light illumination using a diffuser.

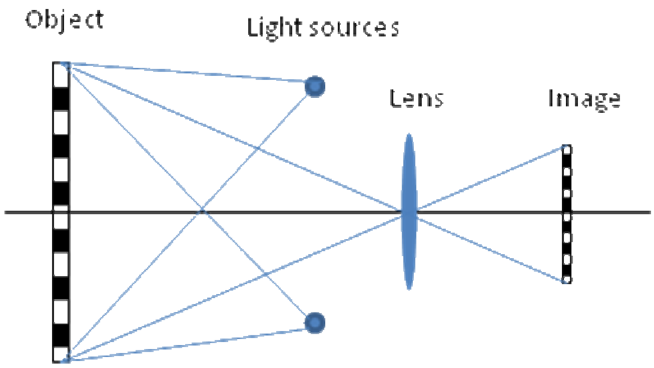


Figure 6. Experimental setup for front-light illumination.

2.6. List of tasks

Task 2

- Measure the distance between two far apart holes as precisely and accurately as you can, and use the result to estimate the separation between any two nearest holes, as well as the average hole diameter, use image 'L2S2T1.jpg'.

Task 3

- Use image 'L2S2T21.jpg' (Backlight Illumination) and 'L2S2T22.jpg' (Frontlight Illumination) and answer the following questions:
  - What is the accuracy of measuring of holes sizes in each case and why?
  - How uniform is the measurement results for each case and why?

2.7. Experimental setup for dark-field illumination

Figure 7 depicts a schematic experimental setup for the inspection of a surface using dark-field front-light illumination. This illumination technique was used for imaging of a circuit board. See image files L2S3T1.jpg and L2S3T2.jpg.

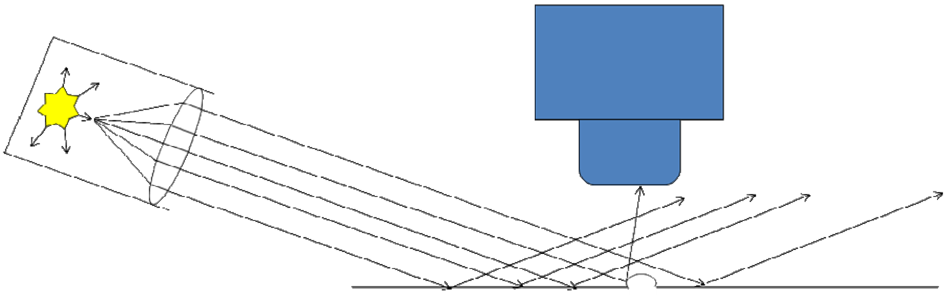


Figure 7. Dark field front-light illumination.

2.8. List of tasks

Task 4

- Use image 'L2S3T1.jpg' and explain which part of the image that is emphasized due to the use of dark-field light and why?

Task 5

- Use image 'L2S3T2.jpg' and find out the settings of the switches using image analysis?

3. Image processing

3.1. Introduction

Image processing is a large area of science and also an active area of research. We can only get minor insight in these technologies by a single lab experiment. We are going to focus on the pre-processing and segmentation of coins depicted in front of a light background. The last task also includes post-processing of segmented image using morphological filtering/analysis.

3.2. Summary of provided images

- L3S1T1.jpg is a picture of a test object for analysing resolution
- L3S1T2.jpg is a noisy image of coins
- L3S1T3.jpg is another noisy image of coins

3.3. List of useful Matlab commands

The following list of commands for Matlab is a hint on how to solve listed tasks.

- imfilter
- imread
- imshow
- rgb2gray
- graythresh
- im2bw
- imhist
- edge
- imopen
- imclose
- bwlabeln
- regionprops

3.4. List of tasks

Task 1

- Pre-process the image 'L3S1T1.jpg' with a filter that computes the mean value of a 3-by-3 pixel window function (2D convolution). What happens with image resolution?
- Compute and visualize the filter's 2D amplitude transfer function using fft analysis. For visualisation, use Matlab function *mesh*. What kind of filter, lowpass-, highpass-, bandpass- or bandstop filter? Explain and analyse.

Task 2

- Pre-process the image 'L3S1T2.jpg' for reduction of image noise using your filter. Compute and visualise global grayscale histograms before and after filtering of image.
- Analyse histograms and experiment on finding a graylevel threshold that generates accurate regions for the coins. Do these experiments both for the filtered and non filtered images?
- Repeat thresholding on both filtered and non filtered images but now with automatic selection of threshold levels using graythresh.
- Which combination of pre-processing and thresholding do you think generates the most accurate result?

Task 3

- The best method from previous Task 2, try it also on image L3S1T3.jpg. Explain the problems that you are now facing.
- Use Matlab function *edge* to find as accurate as possible the edges of coins. You should use and compare different methods for computing image gradients.
- Which method for edge detection gives the most accurate description of coin edges and at the same time least amount of spurious edges?

Task 4

- Apply morphological postprocessing for the removal of spurious image components. Use the best result either from Task2 or Task3 as input for these morphological operations.

4. Image Analysis – Quality inspection of cookies

4.1 Introduction

Assume that a person is sitting beside a conveyer belt coming out of a machine baking cookies. This person's work is to visually inspect cookies looking for the cracked, too small or not circular enough ones. Bad cookies are removed and disposed. Your assignment is to replace this person with a machine vision system capable of doing the same visual inspection automatic. A system sketch of such a system is depicted in Figure 8.

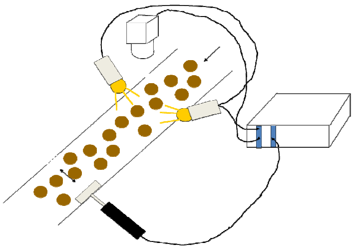


Figure 8. Machine vision system for inspection of cookies.

4.1. Summary of provided images

- image11.jpg to image13.jpg: Images of cookies to be accepted by the inspection system.
- image21.jpg and image22.jpg: some of the cookies in these images should not be accepted.

4.2. Experimental setup

A long white paper was placed on the floor in corridor of an office environment. See Figure 9. Front-side illumination and a camera fixed to a tripod were placed over the white paper. Ginger cookies from ICA were distributed over the paper area. Pieces of cracked cookies, badly shaped and too small cookies were also included as examples of cookies to be rejected by the inspection system. See Figure 10.

Figure 9. Experiment with automatic inspection of cookies.

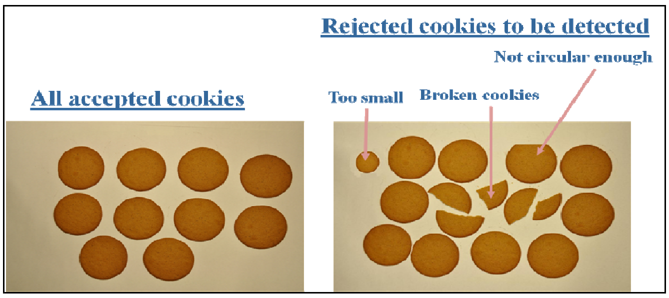


Figure 10. Example of accepted and rejected cookies.

4.3. List of tasks

Your assignment in this lab is to model the algorithm for a machine vision system capable of making decision on whether to accept or reject cookies on the conveyer belt. This assignment is further divided onto Task1 to Task7 depicted in Figure 11. This graph shows a generalised dataflow for a machine vision system also used to define a workflow for your experiments.

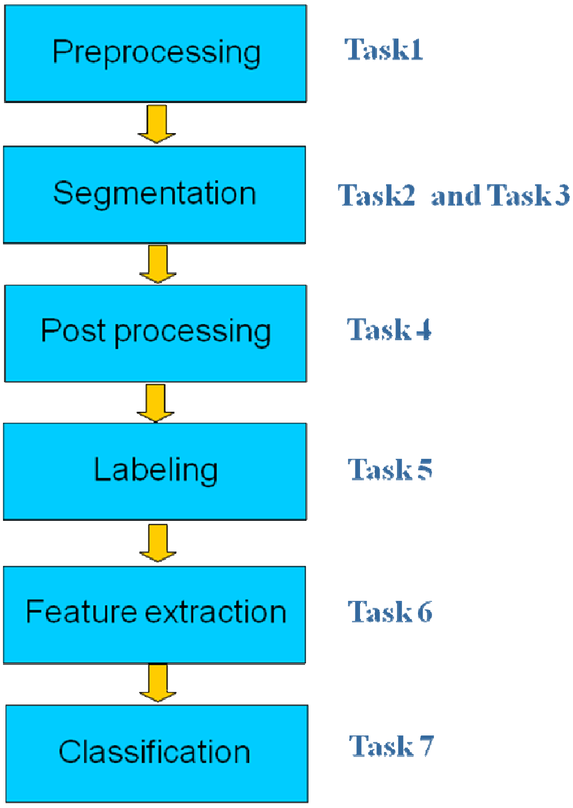


Figure 11. Sequence of computational steps.

Task 1 - *Preprocessing of input colour image*

- Convert the input colour image into a grayscale image. Use the intensity component Y in YCbCr colour model.
- Do you think this image has enough signal in comparison with noise? Or do you need to apply additional pre-filtering to reduce noise. You can understand this also by studying the global intensity histogram. A distinct bimodal histogram having two distinct grayscale classes can easily be segmented.

Task 2 - *Try different methods for segmentation to find the regions of cookies*

- Examine intensity histogram of gray scale image
- Find regions by global fixed value thresholding
- Find regions by using Otsu's method for automatic selection of global thresholds. Look at command graythresh in MatLab
  Otsu, N., "A Threshold Selection Method from Gray-Level Histograms," IEEE Transactions on Systems, Man, and Cybernetics, Vol. 9, No. 1, 1979, pp. 62-66.

Task 3 – *Try different methods for segmentation to find the edges of cookies*

- You can use MatLab command edge and apply different derivative filters such as Sobel, Canny or Prewitt.
- What could be the advantage in finding edges rather than regions?
- Suggest a method to go from edges of cookies to regions. Basically you need to fill the holes.

***Task** 4* – *Morphological post-processing*

- Are the areas of cookies well defined or is image noise disturbing the segmentation?
- How to treat tiny fragments of cookies?
- Can the above possible problems be treated by the use of morphological post-processing applied after segmentation?

***Task** 5* – *Image component labeling*

- Apply component labelling on the segmented image.
  Have a look at command bwlabel in MatLab.
- Apply colour coding of the labelled image.
  Have a look at command label2rgb in MatLab.
- Investigate also dimensions, content and size of generated data structure after component labelling.

***Task** 6* – *Feature extraction*

- Now you need to learn how to compute properties that enable the system to find the cookies to be rejected or accepted.
- This accept-reject must be based on two different scalar properties:
  - C=How circular is the cookie?
  - S=Size of cookie?
- You need to find out how basic region- or gray value features can be applied to capture the listed two properties.
- Compute C and S for all images having only cookies to be accepted.
- Compute C and S for all images having only cookies to be rejected. This might require that you need to manually edit some of the pictures.
- Generate a 2D scatter plot having dimensions C and S. Use different colors for accepted and rejected cookies. Do you get separable data clusters?

***Task** 7* – *Classification of cookies*

- Write a MatLab script that can label all bad cookies with a red letter B. Analyse two methods for classification:
  Method 1: From an analysis of C and S computed for both good and bad cookies, you should be able to formulate logical rules for an accepted or rejected cookie. Scatter plot generated in previous task will help you understand how to formulate the rules.
  Method 2: A minimum distance classifier computes distances from a feature vector to centroids of all classes. The class that has the shortest distance is the class to select. The video presentation about OCR in Lecture 6 is describing in detail this method for classification.

Image Acquisition in 3D using Triangulation

4.4. Introduction

You are now going to practice 3D surface acquisition using laser triangulation. A principle sketch of geometry is shown in Figure 12. An object of height *r* is reflecting light generated by a laser onto the focal plane array at position *d*. An example of a Gaussian shaped light intensity profile generated by a laser source is shown in Figure 13. An elementary image processing operation is to find out the spatial position of the reflected line. Position sensing of such a light reflection can be accomplished at higher resolution than one pixel size. Center Of Gravity (COG) is an algorithm that can be used to weight position by its light intensity. Thresholding at level *Th* as shown in Figure 13 means that only those pixels where light intensity is greater than level *Th* are included into the COG computation. The reason for this thresholding is to exclude those pixels that mostly contribute with noise. The position *d(c)* of a laser line at image column *c* is defined as,

$$d(c) = \frac{\sum_{r=-B}^{B} r \cdot I(r,c)}{\sum_{r=-B}^{B} I(r,c)}, \; 1 \le c \le NoOfColumns$$

This position *d(c)* can then be used to compute the corresponding height *r* of an object by means of triangulation,

$$r = H \cdot \left(1 - \frac{(F_{ZD} - D\tan(\beta)) \cdot (F_{ZD}\tan(\beta) - d)}{(F_{ZD}\tan(\beta) + D) \cdot (F_{ZD} + d\tan(\beta))} \right)$$

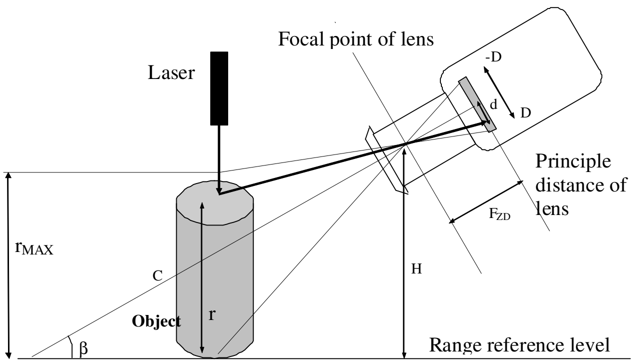


Figure 12. Principle sketch for laser triangulation.

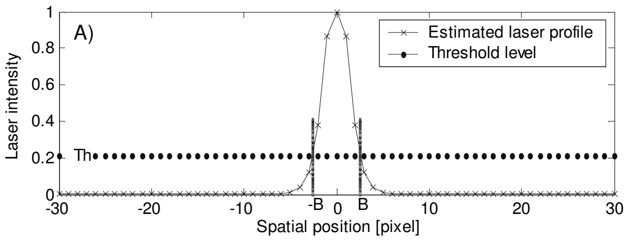


Figure 13. Light intensity profile

In this set of laboratory exercises you are firstly going to experiment on generating a Gaussian shaped light intensity profile using Matlab and then evaluate methods for computation of COG including selection of threshold, *Task 1*. Secondly you are going to apply your signal processing on a sequence of real-world images generated from laser scanning the surface of a piece of toilet paper, *Task 2*.

4.5. Imaging system specification

The following data applies for the image acquisition system shown in Figure 14 that has been used to capture provided images.

- Used monochrome CCD camera : uEye2250 M
    - Number of pixels: 1600 x 1200 (Images are cropped to 1500 x 500)
    - Pixel size: 4.4 x 4.4 um
- Structured linear shaped illumination sources – semiconductor near infrared pulsed laser (wavelength 0.9 µm)
- Motorized translation stages with motion controller driver and GRIB USB interface,
- Scanning step size when acquiring images is 0.5 mm.
- Height scale is 44 µm/pixel
- Focal length is 25 mm
- Entry pupil diameter is 12 mm
- Distance to sample is 250 mm
- Camera angle β is 60 degrees
- Laser line length observed by camera is 65 mm

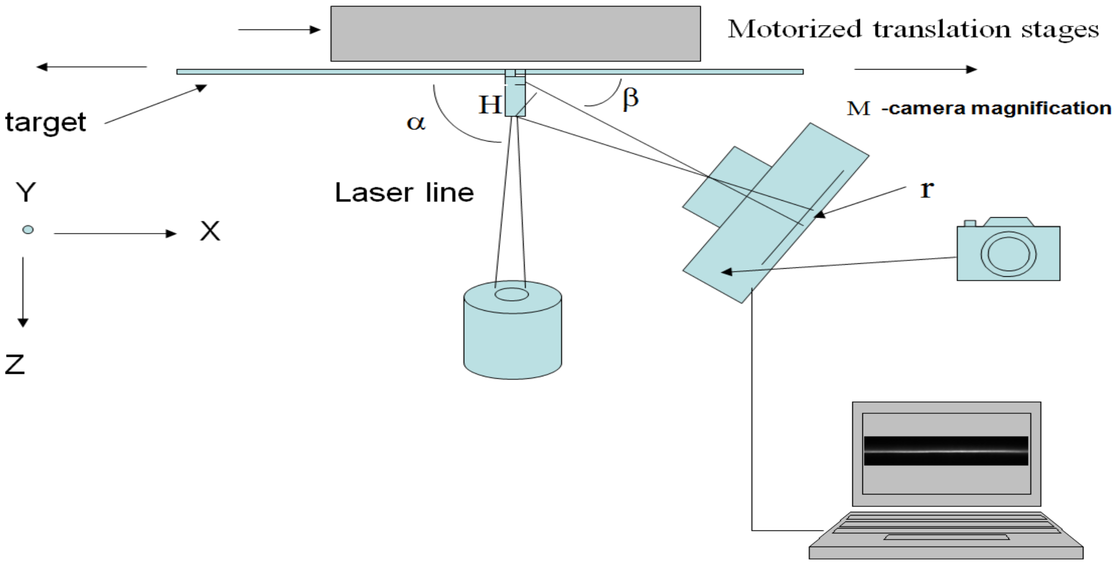


Figure 14. Schematic picture of motorized laser scanner.

4.6. Summary of provided images

- 100 images of laser profiles, *Cam1_2015-04-17_00000.tif* to *Cam1_2015-04-17_00099.tif*

4.7. List of tasks

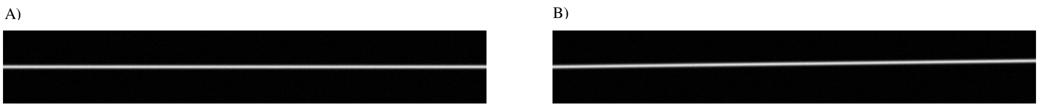


Figure 15. Images of Gaussian intensity lines

Task 1

- Generate synthetic images using Matlab simulation. Generate 20 images having a projected straight line with Gaussian shaped intensity curve and for half widths ranging from 1 to 20 pixels. Firstly, let this line coincide with the horizontal dimension. See Figure 15A. Allow max grayscale intensity of line to reach 90 % of dynamic range. Add Gaussian noise having a variance of 0.1 % of dynamic range. Make also a separate plot of grayscale intensity profile allowing for verification of intensity level and half width. Make another series of 20 images where line is tilted with an angle of 0.7 degrees. See Figure 15B.

- Write a Matlab simulation script that computes COG (Center Of Gravity) in vertical direction across the line and for all image columns along the horizontal direction. Include also the computation of standard deviation of COG output along the line. Include compensation for tilt angle.
- Make an experiment on those 20+20 synthetic images. Compute standard deviation of COG output for lines having different half widths and using different graylevel threshold levels. Analyze results and try to make conclusions on how half width and threshold should be selected in order to get highest possible precision of COG output. How does the tilted line affect optimal selection of threshold and line width?

Task 2

- Compute depth of field (DOF) for the laser scanner using given optical parameter data. Is it enough for scanning a toilet paper?
- Create a MatLab script that reads provided 100 laser profile images for the generation of a range data using COG. Assume a linear height response of the scanner and use given calibration data.
- Visualize the generated range data as a grayscale image. It is preferable to stretch range data such that dynamic range of data is displayed with maximum contrast (without saturation). You need to rescale one dimension of range data to be able to display range as grayscale with both spatial dimensions having the same scale. Can you recognize the decorative structure shown in Figure 16?
- Visualize range data as a 3-dimensional mesh plot. Make sure that all axes have correct scales and units assigned to the plot.

Figure 16. A piece of toilet paper with decorative structure ☺

6 Instructions for reports and oral presentations

You must prepare 15 minutes oral presentations (including questions) for each one of the five labs, plan for 10 minutes presentation and 5 minutes for questions. These presentations must have a disposition corresponding to a full technical report. This means that you need to give an introduction, define the problem, present methods and results, as well as also analyze the results, draw conclusions, and point out possible alternative methods. A seminar will be held at the end of the course, where all lab groups will give their oral presentations. All lab group members must participate actively in the presentations. All members must also be prepared to answer questions and defend your work and results. The oral presentations must be based on PowerPoint slides. The first slide must have the names of all lab group members written on it. Power point slides for all five experiments together with MatLab code must be sent to teacher the day before the seminar. All lab groups will present one lab out of five possible. Which one of the five labs, will be decided by the teacher at the day of the seminar and at the last minute. This means that you need to be prepared to present any of the five labs. All students must attend during whole time of the seminar.

References

[1] Carsten Steger, Markus Ulrich and Christian Wiedermann, *Machine Vision Algorithms and Applications*, WILEY-VCH Verlag GmbH, ISBN 978-3-527-40734-7.

[2] On-line lectures at: http://apachepersonal.miun.se/~bentho/machinevision/index.htm

[3] Data sheet for 25 mm lens, http://www.edmundoptics.com/Documents/Download/380158