Lappeenranta University of Technology
Faculty of Industrial Engineering and Management
Degree Program in Computer Science

Bachelor's Thesis

**Teemu Huovinen**

# SENSITIVITY OF RETINAL IMAGE SEGMENTATION ON GROUND TRUTH ACCURACY

Examiners: Professor Esim Esimerkki
Lasse Lensu D.Sc. (Tech.)

Supervisor: Lasse Lensu D.Sc. (Tech.)

# ABSTRACT

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**Sensitivity of retinal image segmentation on ground truth accuracy**

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2014

25 pages, 64 figures, 1 table, and 2 appendices.

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Keywords: keyword, key, word

Notice that the page, figure, table and appendix counts are for the whole work, including title page, appendices, figures in appendices, etc. You have to count the numbers yourself, except for pages. Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

# TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
Tuotantotalouden tiedekunta
Tietotekniikan koulutusohjelma

Teemu Huovinen

**Silmänpohjakuvien segmentoinnin herkkyys pohjamerkintöjen tarkkuudelle**

Kandidaatin työ

2014

25 sivua, 64 kuvaa, 1 taulukko ja 2 liitettä.

Tarkastajat: Professori Esim Esimerkki
TkT Lasse Lensu

Hakusanat: avainsana, avain, sana
Keywords: keyword, key, word

Tähän kirjoitetaan ytimekäs tiivistelmä: tausta, tavoite, tulokset ja johtopäätökset. Tiivistelmässä kannattaa käyttää lyhyen nasevia lauseita. Itse tekstissä voi käyttää monimutkaisempia lauseita. Tiivistelmä-sivu on yksi sivu ja tiivistelmäteksti on yksi kappale, ei useita kappaleita. On hyvä kertoa työn tavoitteet. Mikäli työ sisältää oleellisia aiheen rajauksia, ne kannattaa mainita jo tiivistelmässä. Työn tulokset ja johtopäätökset luetellaan lukijan mielenkiinnon lisäämiseksi. Opinnäytetyö kirjoitetaan passiivissa tyyliin “tässä työssä tutkitaan..” aktiivin sijaan “minä tutkin...” ja marginaalit tasataan aina sekä vasemmalle että oikealle. Työn numerointi aloitetaan kansilehdeltä, mutta tätä roomalaista numeroa ei merkitä näkyviin.

# PREFACE

Tässä voidaan mainita työn tekopaikka, kiittää työtä tukeneita henkilöitä ja muita tahoja, jne. tyyliin “Työ on tehty Lappeenrannan teknillisen yliopiston ... Kiitän työkavereita ja rakasta vaimoani tuesta ...”

I wish to thank my supervisor

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Finally, thank you to

Lappeenranta, October 19th, 2014

*Teemu Huovinen*

# CONTENTS

# ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| **AMD** | Advanced Micro Devices, Inc. |
| **API** | application programming interface |
| ${}^{A}\boldsymbol{x}$ | vector $\boldsymbol{x}$ given in coordinate frame A. |
| $\boldsymbol{X}$ | a matrix |

# 1 INTRODUCTION

## 1.1 Background

The growing amount of diabetes patients and (arguably) more importantly the estimated amount of undiagnosed patients motivate the research for an effective mass screening method for early detection of diabetes. Diabetic retinopathy is a complication of diabetes that causes abnormalities in the eye, and detecting these abnormalities in the eye fundus is a promising mass screening method. Images where ophthalmologists have marked these abnormalities, such as exudates, are used as ground truths in eye fundus image segmentation research.

Optimal ground truth would be a pixel-accurate binary representation of the abnormalities, but as ground truths are done by a human hand, such accuracy is unrealistic. Because the marking of an accurate ground truth takes a good amount of time and patience, we often have to settle for rough markings of the present abnormalities. Clusters of exudates are circled, rather than each small finding specified separately.

## 1.2 Objectives and Restrictions

The objective of this thesis is to evaluate how big of an impact inaccurate ground truth has on various image features and segmentation methods.

Ground truth accuracy is explored only from the perspective of exudate detection, and Bristol database is used as it has accurate ground truths of exudates. Blood vessel detection is explored only to create a mask for them. A rough method for optic disk detection is also implemented as a preprocessing step for masking reasons.

Both supervised and unsupervised segmentation methods are used. In supervised methods, ground truths are used to label observations as either exudate or background. In unsupervised methods, ground truth is used to evaluate segmentation results. Best parameters for each method are chosen based on their performance.

## 1.3 Structure of the Thesis

Section 2 takes a look at the different features of eye fundus images, and how they are relevant in this thesis. It also explains the theory behind the applied pre-processing and segmentation methods. Section 3 details how sensitivity analysis is done in this thesis, and also explains the used evaluation methods. Section 4 describes the experiments in detail, and presents the results for each experiment. Section 5 sums up and interprets the results, and discusses the impact of this thesis and possible future work this thesis might invoke.

# 2 SEGMENTATION OF RETINAL IMAGES

Korkeemmalta tasolta, mikä työssä on tehtävä (myös herkkyysanalyysi). Kirjallisuuskatsaus.

## 2.1 Optic disc detection

Optic disc is very similar to exudates in terms of color and intensity, so detection and masking of the optic disk is an important preprocessing step in exudate detection. There are papers dedicated to the localisation of the optic disk [1], and it is also covered in papers concerning the detection of other parts of the eye fundus, such as exudates [2].

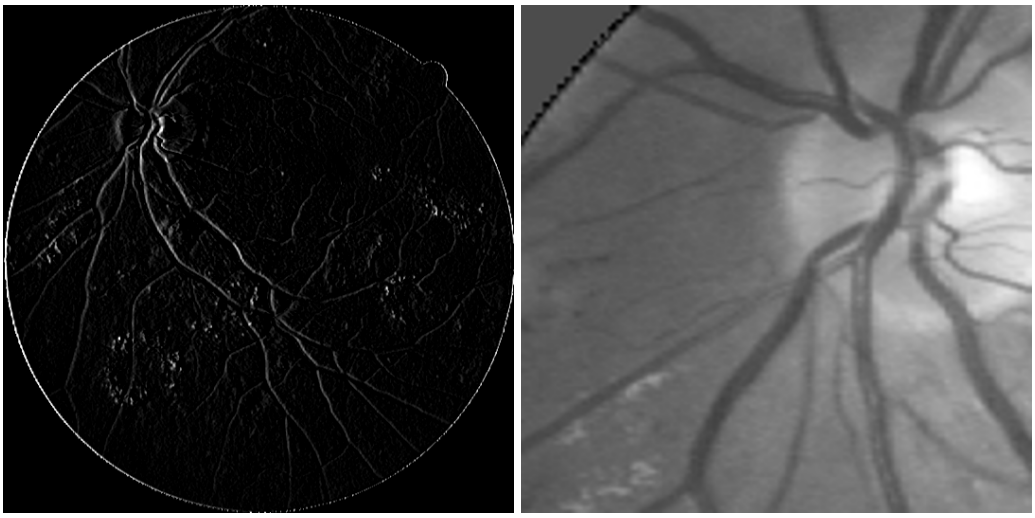
This method is based on the brightness of the optic disk, and the vertical blood vessels inside it. The horizontal image gradient is calculated using Sobel gradient operator, the result is shown in Figure 1a. Image is then divided into slightly overlapping square areas with a side of 140 pixels (size is adjusted when operating close to image borders). The area with the highest sum of gradients is considered as region of interest, i.e. to hold the optic disk. This is because the dark blood vessels inside the bright optic disk result in a strong horizontal gradient. Images with a "camera glare",i.e. a high intensity strip in the corner of the eye fundus are problematic, as that area also has a high horizontal gradient. Region of interest is shown in Figure 1b.

Inside this area of highest sum of horizontal gradients, the pixel with the highest intensity is considered to be inside the optic disk. This pixel is then used as a center of a circle that will mask out the optic disk. Final masking result is shown in Figure 1c.

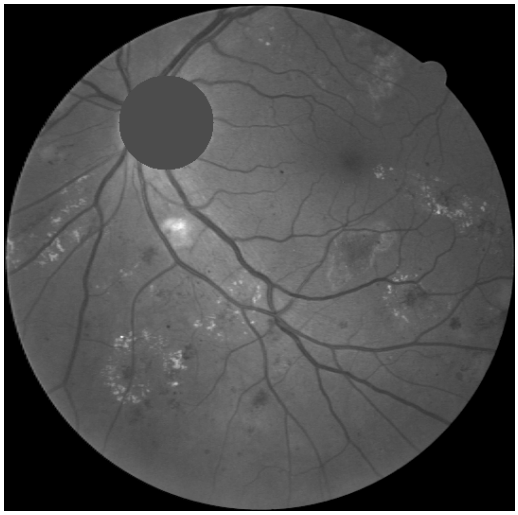
## 2.2 Blood vessel detection

The purpose of blood vessel detection in this thesis is to create a mask, and to use that mask to remove false positives from exudate segmentation results. For example, edge detection techniques often highlight the borders of vessels as well as exudates.

The mask is formed by first using adaptive histogram equalization to enhance contrast in the green channel of the image, the result for this is shown in Figure 2a. This contrast enhanced image is then thresholded with Otsu's method, which separates the image into



(a) (b)

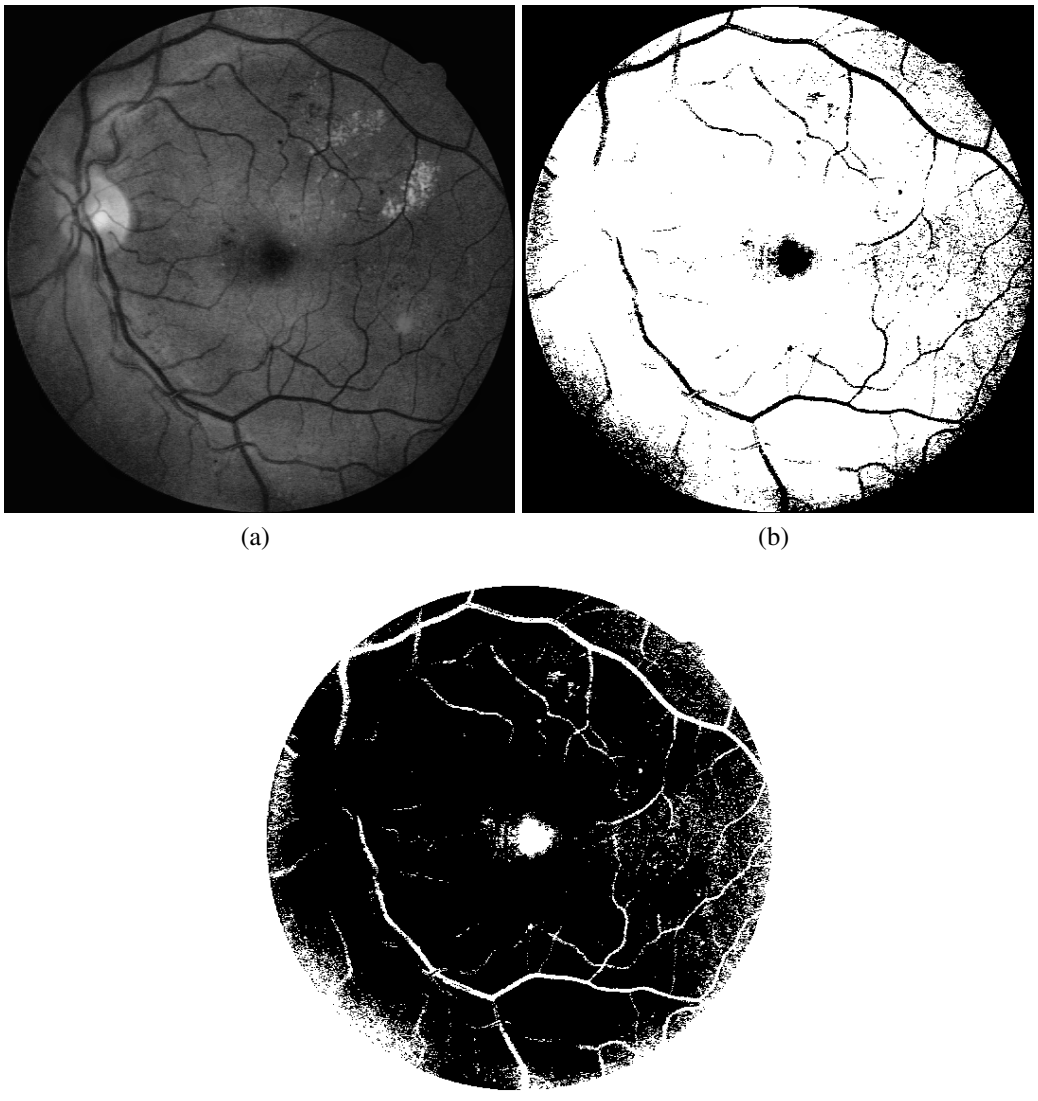


(c)

**Figure 1.** Locating and masking the optic disk: (a) Horizontal gradient (b) Region of interest (c) Optic disk masked out

foreground and background by minimizing the intra-class variance. This results in all the vessels and other darker areas showing as black (or background), and all brighter areas as white (foreground). This is shown in Figure 2b. To create a binary mask of the darker areas, we use the complement of this thresholded image. Final version of the mask is shown in Figure 2c.

This method is inadequate for blood vessel detection as it also includes other darker areas of the image, such as the fovea. As a mask however, it clearly reduces the amount of false positives in exudate segmentation results. It also doesn't remove true positives, as only the darker areas of the image are included in the mask.



(a) (b)

(c)

**Figure 2.** Phases in creating the blood vessel mask: (a) Adaptive histogram equalization (b) Thresholding using Otsu's method (c) Final mask, complement of thresholded image

## 2.3 Examples of Equations

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First the derivative images[2]

$$\begin{aligned} I_x = \frac{\partial I}{\partial x} &= I * \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \\ I_y = \frac{\partial I}{\partial y} &= I * \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \end{aligned} \tag{1}$$

of the input image $I(x, y)$ are computed, where $*$ denotes convolution. The sum of squared errors generated by a small dislocation $\Delta x, \Delta y$ can be written as

$$E(\Delta x, \Delta y) = A(\Delta x)^2 + 2C\Delta x\Delta y + B(\Delta y)^2 \tag{2}$$

where

$$\begin{aligned} A &= I_x^2 * w \\ B &= I_y^2 * w \\ C &= (I_x I_y) * w \end{aligned} \quad . \tag{3}$$

And a demonstration of subfigures in Figure 3. We can also reference a single subfigure Figure 3b. And an equation, like Eq. 2.

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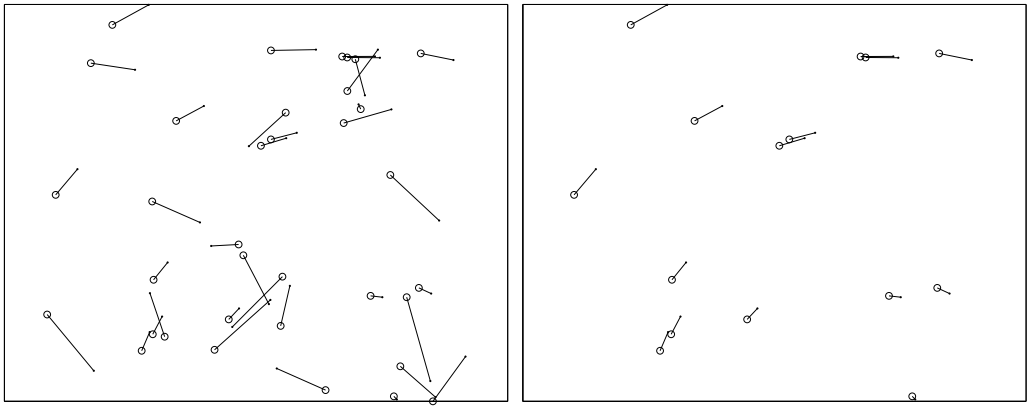
[1] Testing footnotes.

[2] You should not usually use footnotes.



(a) (b)

**Figure 3.** Apparent motion of a set of point trackers. Positions in frame $t$ are circles and positions in frame $t+1$ are dots: (a) All trackers; (b) Only coherent trackers.

And then some nice math:

$$
\begin{aligned}
L_{\mathrm{o}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda, \boldsymbol{\theta}) &= \iint\limits_{\boldsymbol{\phi}\in\Omega_{\mathrm{i}}} \left[\rho_{\mathrm{d}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda) + \rho_{\mathrm{s}}(\boldsymbol{\theta}, \boldsymbol{\phi})\right]\, L_{\mathrm{i}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda, \boldsymbol{\phi})\, \cos\boldsymbol{\phi}\, \mathrm{d}\boldsymbol{\phi} \\
&= \iint\limits_{\boldsymbol{\phi}\in\Omega_{\mathrm{i}}} \rho_{\mathrm{d}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda)\, L_{\mathrm{i}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda, \boldsymbol{\phi})\, \cos\boldsymbol{\phi}\, \mathrm{d}\boldsymbol{\phi} \\
&\quad + \iint\limits_{\boldsymbol{\phi}\in\Omega_{\mathrm{i}}} \rho_{\mathrm{s}}(\boldsymbol{\theta}, \boldsymbol{\phi})\, L_{\mathrm{i}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda, \boldsymbol{\phi})\, \cos\boldsymbol{\phi}\, \mathrm{d}\boldsymbol{\phi} \\
&= \rho_{\mathrm{d}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda) \iint\limits_{\boldsymbol{\phi}\in\Omega_{\mathrm{i}}} L_{\mathrm{i}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda, \boldsymbol{\phi})\, \cos\boldsymbol{\phi}\, \mathrm{d}\boldsymbol{\phi} \\
&\quad + \iint\limits_{\boldsymbol{\phi}\in\Omega_{\mathrm{i}}} \rho_{\mathrm{s}}(\boldsymbol{\theta}, \boldsymbol{\phi})\, L_{\mathrm{i}}({}^{\mathrm{S}}\boldsymbol{x}, \lambda, \boldsymbol{\phi})\, \cos\boldsymbol{\phi}\, \mathrm{d}\boldsymbol{\phi} \quad .
\end{aligned}
\tag{4}
$$

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$$\begin{bmatrix} \hat{V}^1 \\ \hat{V}^2 \\ \hat{V}^3 \end{bmatrix} \approx \begin{bmatrix} \frac{\langle \tau^1 qL, \tau^1 \rangle}{\|\tau^1 qL\|^2} & \frac{\langle \tau^2 qL, \tau^1 \rangle}{\|\tau^2 qL\|^3} & \frac{\langle \tau^3 qL, \tau^1 \rangle}{\|\tau^3 qL\|^4} \\ \frac{\langle \tau^1 qL, \tau^2 \rangle}{\|\tau^1 qL\|^5} & \frac{\langle \tau^2 qL, \tau^2 \rangle}{\|\tau^2 qL\|^6} & \frac{\langle \tau^3 qL, \tau^2 \rangle}{\|\tau^3 qL\|^7} \\ \frac{\langle \tau^1 qL, \tau^3 \rangle}{\|\tau^1 qL\|^8} & \frac{\langle \tau^2 qL, \tau^3 \rangle}{\|\tau^2 qL\|^9} & \frac{\langle \tau^3 qL, \tau^3 \rangle}{\|\tau^3 qL\|^2} \end{bmatrix} \begin{bmatrix} V^1 \\ V^2 \\ V^3 \end{bmatrix} , \tag{5}$$

Give URL's like this: `http://www.oonumerics.org/blitz/`. That way they may work as links in PDF.

# 3 SENSITIVITY ANALYSIS OF IMAGE FEATURES

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An example of a table is presented in Table 1.

**Table 1.** Method parameters for all tests.

| | | |
|---|---|---|
| minimum distance | 10 | px |
| maximum number of point trackers | 50 | |
| maximum time between point tracker resurrections | 10 | fr |
| minimum number of point trackers until resurrection | 20 | |
| template matching RMSE threshold | 32 | |
| template size | 9 by 9 | px |
| search distance along both axes | 7 | px |
| weak corner eigenvalue threshold | 0.01 | |
| RANSAC inlier error threshold | 1.4 | px |
| RANSAC maximum number of attempts | 40 | |
| RANSAC immediate acceptance threshold, inliers | 35 | |
| minimum number of RANSAC inliers | 8 | |

You can reference to Appendix 2, and in there, Figure A2.1. Hey, let us throw here another completely irrelevant reference, see the book [3].

# 4 EXPERIMENTS AND RESULTS

## 4.1 Retinal Image Databases

## 4.2 The Ground Truth

## 4.3 Experiment 1

## 4.4 Experiment 2

# 5 DISCUSSION

We have to discuss what we learned.

Notice the automatic page breaks.

## 5.1 Segmentation Results

## 5.2 Sensitivity of Image Features

## 5.3 Future Work

It is always nice to give some ideas for the future.

# 6 CONCLUSIONS

Finally the conclusions. This is more compact that the Discussion, a sort of summary about how things went on a general level.

Now you can delete all this crap content and write your own. Have fun!

# REFERENCES

[1] Sribalamurugan Sekhar, Waleed Al-Nuaimy, and Asoke K Nandi. Automated localisation of retinal optic disk using hough transform. In *Biomedical Imaging: From Nano to Macro, 2008. ISBI 2008. 5th IEEE International Symposium on*, pages 1577–1580. IEEE, 2008.

[2] Thomas Walter, J-C Klein, Pascale Massin, and Ali Erginay. A contribution of image processing to the diagnosis of diabetic retinopathy-detection of exudates in color fundus images of the human retina. *Medical Imaging, IEEE Transactions on*, 21(10):1236–1243, 2002.

[3] R.A. Adams. *Calculus*. Addison Wesley Longman, Inc, 4th edition, 1999. ISBN 0-201-39607-6.

## Appendix 1. Appendix Guidelines

The appendices part starts with the command `\appendix`. Then, each appendix must be started with `\section{Appendix Name}` and ended with `\sectionend` to have the continues/continued markings right. For example, see the multi-page appendices after this one.

## Appendix 2. Frame Schematics

This is an appendix. If you need more appendices, just make a new section here (the `section` command).

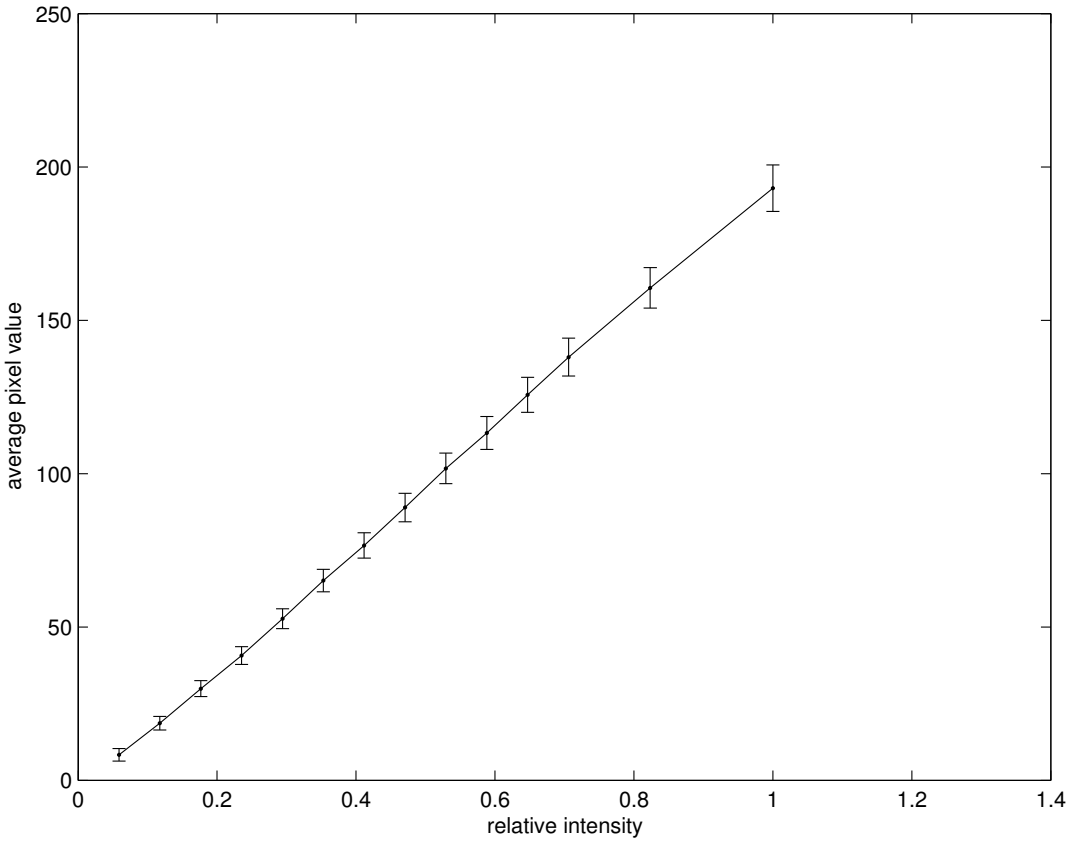


**Figure A2.1.** Overall design, only one half drawn.

huhu

Reference testing: Figures A2.1, A2.2, and A3.1. Table A3.1.

(continues)

# Appendix 2. (continued)

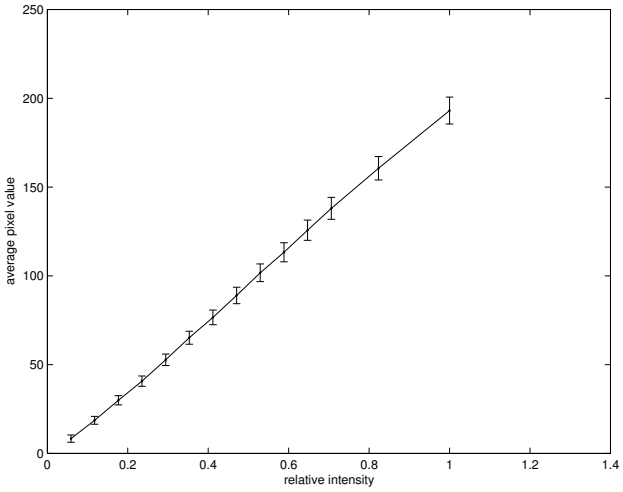


**Figure A2.2.** Another picture.

## Appendix 3. The Second

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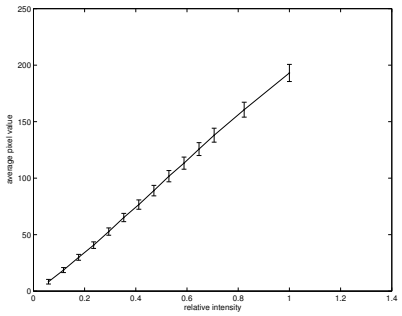


**Figure A3.1.** The same picture once more.

**Table A3.1.** Appendix test table.

| | | |
|---|---|---|
| minimum distance | 10 | px |

(continues)

## Appendix 3. (continued)

Aaand two more pages, to test the continues/continued marks.

(continues)

## Appendix 3. (continued)

Aaand one more page, to test the continues/continued marks.