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Enhancement of Footwear Impressions

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Rebeka Koszticsak, Bsc
Matrikelnummer 01325492

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der Technischen Universität Wien

Betreuung: Ao.Univ.Prof. Dipl.-Ing. Dr.techn. Robert Sablatnig
Mitwirkung: Dipl.-Ing. Manuel Keglevic

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Rebeka Koszticsak	Robert Sablatnig

Technische Universität Wien
A-1040 Wien ▪ Karlsplatz 13 ▪ Tel. +43-1-58801-0 ▪ www.tuwien.ac.at

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Rebeka Koszticsak, Bsc
Registration Number 01325492

to the Faculty of Informatics

at the TU Wien

Advisor: Ao.Univ.Prof. Dipl.-Ing. Dr.techn. Robert Sablatnig
Assistance: Dipl.-Ing. Manuel Keglevic

Vienna, 4th January, 2020

Rebeka Koszticsak   Robert Sablatnig

Technische Universität Wien
A-1040 Wien ▪ Karlsplatz 13 ▪ Tel. +43-1-58801-0 ▪ www.tuwien.ac.at

Erklärung zur Verfassung der Arbeit

Rebeka Koszticsak, Bsc
Address

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Wien, 4. Jänner 2020

Rebeka Koszticsak

Danksagung

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Kurzfassung

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Abstract

Shoeprint images are one of the most commonly secured evidences on crimescenes. Even though automatic shoeprint processing is a highly researched topic, the final identifacion is usually done by human forensic experts. The two main steps of shoeprint identification are enhancement and matching.

In this thesis the possibilities for enhancement of shoeprint samples from a real-life dataset are investigated. The main challange of this task is to correctly filter the pattern regardless the versitile, possibly heavily structured and clutterd noise on the samples. Two approaches are examined, pattern enhancement and noise suppression. Among fully automated methods, a semi-automated technique is also tested, where user input is required for noise separation.

The main goal of this work is to find a universal approach which is able to filter and enhance the shoeprint data even in the presence of noise and the possible low image quality. Based on the experiences acquired while investigating the possible techniques a new noise-supression pipeline for shoeprint images is introduced. The noisy pixels are identified based on the Fourier-Mellin features of their multi-sized neighborhood. In the same time a model is built about the average appearance of noise, to eliminate that structure from the foreground as well. Additionally a gradient based line detector is also applied and the edge structures of the shoeprint are clustered to distinguish between pattern and noise edges. The experimental results show that the processed images are clearer, the pattern is sharper whereas the noise is either completely eliminated in the background or suppressed in the foreground. Furthermore based on the results of three differenet basic image descriptor features, the enhanced shoeprints have higher matching rate to their ground-thruth samples than the original images.

Contents

Kurzfassung **xi**

Abstract **xiii**

Contents **xv**

1 Introduction **1**
1.1 Problem Definition 2
1.2 Challanges 2
1.3 Contribution 3
1.4 Structure of the Work 4

2 Related Work **7**

3 Pattern Enhancement **9**

4 Fully Automated Noise Supression **11**

5 Semi-Automated Noise Supression **13**

6 Results and EValuation **15**

7 Future Work **17**

8 Conclusion **19**

9 Introduction to LaTeX **21**
9.1 Installation 21
9.2 Editors 21
9.3 Compilation 22
9.4 Basic Functionality 23
9.5 Bibliography 24
9.6 Table of Contents 25
9.7 Acronyms / Glossary / Index 25
9.8 Tips 25

9.9 Resources 26

List of Figures **29**

List of Tables **31**

List of Algorithms **33**

Index **35**

Glossary **37**

Acronyms **39**

Bibliography **41**

CHAPTER 1

Introduction

Shoeprints found on crimescenes can be important hints or evidences in a criminal investigation [KYZ14]. Event though on one thrid [Ale96] of crimescenes usable shoepatterns can be secured, there is no fully automatized algorithm available yet, which is able to identify and match those prints with the original shoe sole. Because of that human power is needed [WSYZ14] to recognize and analyze the found patterns. The work of forensic experts is not only time consuming and expensive, there is no guarantee about the objectivness of the final outcome[GBCN08], furthermore the stages of the human matching process are unclear and not necessarily reproducible.

There is an excessive amount of research already done [RBCP19] in order to help or repleace the work of forensic experst. There is however no algorithm published yet, which can be relaiably used in varying conditions and sample quality. One reason for that are the already mentioned versitile conditions, the features and properties of the pattern on the shoe, like age, material, etc., the characteristics of the ground where the shoeprint is left and enviromental conditions like for example the weather highly influence the overall quality of the acquired sample. Those high amount of factors result in changing appearance of the prints of the same shoe causing high intra class variance while clustering. Additionally there is a lack of universal, wide ranged database [RBCP19] which correctly depicts the common scenarios occuring on real-life crime scenes.

In 2014 a new database, called FID-300 [KAV14] was released which aims to solve the database problem described above. It contains over 1000 reference shoeprint patterns acquired in a laboratory. Moreover the database introduces 300 new shoeprint samples collected by the police providing an insight on images forensic experts are working on the daily basis.

1.1 Problem Definition

There are two main stages of automatic shoeprint identification, filtering, where the shoeprint pattern is separated from background and enhanced as well, and matching where the corresponding shoe is determined. Instead of automatizing the entire shoeprint recogition pipeline this work only focuses on the possible ways of icreasing the sample quality. Because of the mentioned absence of general, appropiate database it is difficult to compare the already available methods. Furthermore it is also challanging to estimate which one is applicable in a real-life scenario. In this thesis multiple possible enhancing techniques are developed and tested in order to find a method which is able to cope with samples taken from real crime scenes.

For evaluation and testing the FID-300 database is used. The dataset contains both in a laboratory acquired as well as on a crime secured shoeprint patterns. The goal of this work is to define an image processing pipeline which is able to correctly identify and enhance the shoepatterns and eliminate or suppress the noise on the pattern samples regardless the quality of the image. A secondary objective is to gain an overview about the algorithms already published, and make an estimation which methods are applicable in real-life scenarios based on their performance on the FID-300 database.

1.2 Challanges

There are two main obsticles in the topic of shoeprint enhancement and in automatic shoeprint matching in general, the versitile image quality and appearance and the lack of universal and wide database. The shoeprint patterns are varying, there are approaches available which build models for given structures of the shoeprint [TSKC10], [AK17], but no detailed, uniform representation for the entire shoeprint is possible. Moreover there is a high inference of noise from multiple sources. The ground where the shouprint is found is considered as noise expect in the rear case when it is left on a non changing, even surface. The produced print of the same shoepattern varys on different type of surface. Additionally the roughness and unevenness of a given type of surface also distorts the original pattern. Furthermore other objects on the ground, on or behind the left shoeprint can cover or distort the original pattern, or they can prevent to leave a print on their area completely. Besides that the pattern on the original shoe can also be distorted or modified compared to the new version. Distortions caused by usage are valuable information about the owner, on the other hand they make it more difficult to match the pattern with their unused pairs. Additional objects between the structures of the shoeprint also alter the original appearance. Lastly, there are multiple shoeprint securing methods producing different results for the same print [KS17]. The shoeprint lifting technique used depends on the properties of the ground. Those two factors, the securing method and the floor, also determine if the positive or the negative, the actual pattern or the space between the shoeprint structures, image is captured.

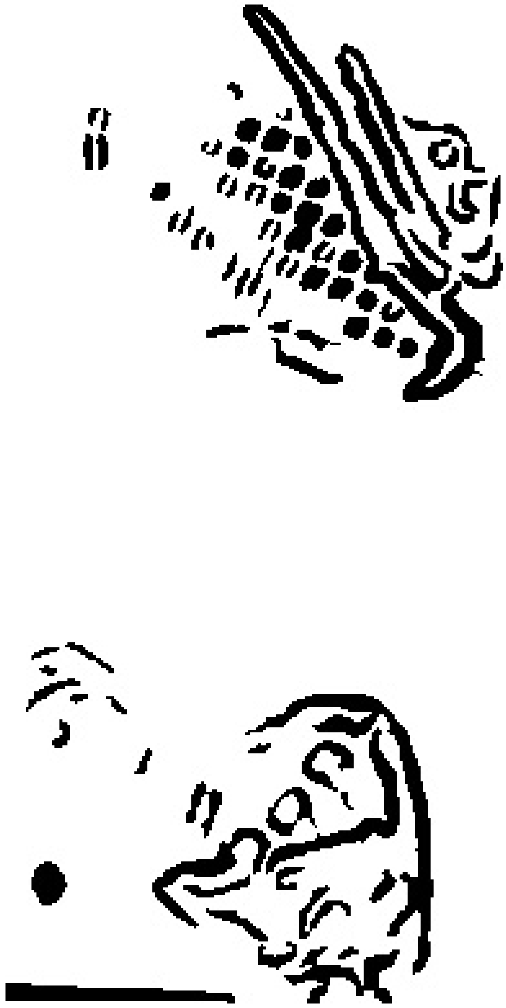
The non-existing universal database causes that two published methods are difficult to compare based on their results since they are using different testing images. The used dataset is not necessarily published [KS17], [DCC09] making it impossible to reproduce the reulst in those cases. Additionally the handcrafted databases can be biased, and allow such restrictions and modifications which do not correlate with real-life scenarios [RBCP19]. The used samples are either synthetically generated and computationally distorted [DCFR05], [GBCN08] or exlude low quality and noisy images [DCC09], [TSKC10]. Because of that it is difficult to compare their performance and to estimate which one of the published approaches are applicable on the FID-300 database. Furthermore it is challanging to plan a new algorithm based on the published results because their lack of a uniform baseline.

1.3 Contribution

In this thesis the possible ways of enhancing a shoeprint images are discussed. Because of the known issues on database multiple approaches are implemented, discussed and evaluated. The two ways to increase the quality of a given shoeprint sample is to enhance the pattern regardless of the noise and to supress or eliminate the noise without losing any of pattern information. Along fully-automated methods semi-automated possibilities are also considered. Three different approaches are introduced and examined for their performance on real-life image samples.

Finally a new semi-autoamted framework is given which is evaluated on the FID-300 database. In the first step user ipnut about the noise is required. The input is separated into tiles, and the subparts are compared based on the Fourier-Mellin features to the region of the use input. In that way the background is separated from the foreground and the average appearance of the image is calculated. Since noise appears on the pattern as well, the distorted parts are corrected based on the calculated noise model. After that gradient based line detection is perfromed and the results are separated into clusters where pattern and noise classes are defined and candidates of the latter are eliminated. The final image is thresholded to create a binary image, where the shoeprint is clearly visible and recognizable whereas the clutter is supressed on the pattern and eliminated in the background of the image. Throughout the whole processing pipeline morphological opeartions and small structure elimination is applyed multiple times. First when a mask for background is built, and also in the end of the pipeline to eliminate small inconsistencies on the pattern. Experimental results show, that the enhanced images are clearer, the background is successfully eliminated and the shoeprint pattern is less noisy than on the original images. Figure 1.1 shows an example sample from the FID-300 database 1.1a and the enhanced images 1.1b with the proposed algorithm. Moreover the matching of the sample and the enhanced images with their in a laboratory lifted pair according to basic image features such as SIFT and SURF indicate that the improved images have a better matching rate than its original version.

(a) Example image from the FID-300 database



(b) Enhanced image

Figure 1.1: Result of the proposed algorithm

1.4 Structure of the Work

To gain an overview about the research already done the followong section, Capter 2, gives a review about the literature. Along papers published in the topic of shoeprint identification, matching and enhancement, research of similar domains is presented as well. Fields of fingerprint processing and tattoo identification is also overviewed for possibilities of using the tecniques in the given problem. Furthermore natural image enhancement and denoising tecniques are revised as well.

In Chapter 3, 4 and 5 the approaches for enhancement are given and discussed if they are applicable for real-life forensic images. Chapter 3 presents and evaluates a possible way for pattern enhancement. Chapter 4 and 5 describes an automated and a semi-automated noise supression pipeline respectively. In Chapter 5 the new algorithm for enhancing real-life crimescene shoeprint impressions is proposed. Details on implementation are revealed as well.

In Chapter 6 experimental results are shown and the proposed algorithm is evaluated. In Chapters 7 and 8 prospective future work is discussed and the final conclusion is given.

CHAPTER 2

Related Work

CHAPTER 3

Pattern Enhancement

CHAPTER 4

Fully Automated Noise Supression

CHAPTER 5

Semi-Automated Noise Supression

CHAPTER 6

Results and EValuation

CHAPTER 7

Future Work

CHAPTER 8

Conclusion

CHAPTER 9

Introduction to LaTeX

Since LaTeX is widely used in academia and industry, there exists a plethora of freely accessible introductions to the language. Reading through the guide at `https://en.wikibooks.org/wiki/LaTeX` serves as a comprehensive overview for most of the functionality and is highly recommended before starting with a thesis in LaTeX.

9.1 Installation

A full LaTeX distribution consists of not only of the binaries that convert the source files to the typeset documents, but also of a wide range of packages and their documentation. Depending on the operating system, different implementations are available as shown in Table 9.1. **Due to the large amount of packages that are in everyday use and due to their high interdependence, it is paramount to keep the installed distribution up to date.** Otherwise, obscure errors and tedious debugging ensue.

9.2 Editors

A multitude of TeX editors are available differing in their editing models, their supported operating systems and their feature sets. A comprehensive overview of editors can

Distribution	Unix	Windows	MacOS
TeX Live	**yes**	yes	(yes)
MacTeX	no	no	**yes**
MikTeX	no	**yes**	no

Table 9.1: TeX/LaTeX distributions for different operating systems. Recomended choice in **bold**.

	Description
1	Scan for refs, toc/lof/lot/loa items and cites
2	Build the bibliography
3	Link refs and build the toc/lof/lot/loa
4	Link the bibliography
5	Build the glossary
6	Build the acronyms
7	Build the index
8	Link the glossary, acronyms, and the index
9	Link the bookmarks

	Command	
1	`pdflatex.exe`	`example`
2	`bibtex.exe`	`example`
3	`pdflatex.exe`	`example`
4	`pdflatex.exe`	`example`
5	`makeindex.exe`	`-t example.glg -s example.ist` `-o example.gls example.glo`
6	`makeindex.exe`	`-t example.alg -s example.ist` `-o example.acr example.acn`
7	`makeindex.exe`	`-t example.ilg -o example.ind example.idx`
8	`pdflatex.exe`	`example`
9	`pdflatex.exe`	`example`

Table 9.2: Compilation steps for this document. The following abbreviations were used: table of contents (toc), list of figures (lof), list of tables (lot), list of algorithms (loa).

be found at the Wikipedia page `https://en.wikipedia.org/wiki/Comparison_of_TeX_editors`. TeXstudio (`http://texstudio.sourceforge.net/`) is recommended. Most editors support the scrolling the typeset preview document to a location in the source document by `Ctrl` clicking the location in the source document.

9.3 Compilation

Modern editors usually provide the compilation programs to generate Portable Document Format (PDF) documents and for most LaTeX source files, this is sufficient. More advanced LaTeX functionality, such as glossaries and bibliographies, needs additional compilation steps, however. It is also possible that errors in the compilation process invalidate intermediate files and force subsequent compilation runs to fail. It is advisable to delete intermediate files (`.aux`, `.bbl`, etc.), if errors occur and persist. All files that are not generated by the user are automatically regenerated. To compile the current document, the steps as shown in Table 9.2 have to be taken.

9.4 Basic Functionality

In this section, various examples are given of the fundamental building blocks used in a thesis. Many LaTeX commands have a rich set of options that can be supplied as optional arguments. The documentation of each command should be consulted to get an impression of the full spectrum of its functionality.

9.4.1 Floats

Two main categories of page elements can be differentiated in the usual LaTeX workflow: *(i)* the main stream of text and *(ii)* floating containers that are positioned at convenient positions throughout the document. In most cases, tables, plots, and images are put into such containers since they are usually positioned at the top or bottom of pages. These are realized by the two environments `figure` and `table`, which also provide functionality for cross-referencing (see Table 9.3 and Figure 9.1) and the generation of corresponding entries in the list of figures and the list of tables. Note that these environments solely act as containers and can be assigned arbitrary content.

9.4.2 Tables

A table in LaTeX is created by using a `tabular` environment or any of its extensions, e.g., `tabularx`. The commands `\multirow` and `\multicolumn` allow table elements to span multiple rows and columns.

Position		
Group	Abbrev	Name
Goalkeeper	GK	Paul Robinson
Defenders	LB	Lucus Radebe
	DC	Michael Duburry
	DC	Dominic Matteo
	RB	Didier Domi
Midfielders	MC	David Batty
	MC	Eirik Bakke
	MC	Jody Morris
Forward	FW	Jamie McMaster
Strikers	ST	Alan Smith
	ST	Mark Viduka

Table 9.3: Adapted example from the LaTeXguide at `https://en.wikibooks.org/wiki/LaTeX/Tables`. This example uses rules specific to the `booktabs` package and employs the multi-row functionality of the `multirow` package.

9.4.3 Images

An image is added to a document via the `\includegraphics` command as shown in Figure 9.1. The `\subcaption` command can be used to reference subfigures, such as Figure 9.1a and 9.1b.

(a) The header logo at text width.

(b) The header logo at half the text width.

Figure 9.1: The header logo at different sizes.

9.4.4 Mathematical Expressions

One of the original motivation to create the TeX system was the need for mathematical typesetting. To this day, LaTeX is the preferred system to write math-heavy documents and a wide variety of functions aids the author in this task. A mathematical expression can be inserted inline as $\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6}$ outside of the text stream as

$$\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6}$$

or as numbered equation with

$$\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6}. \tag{9.1}$$

9.4.5 Pseudo Code

The presentation of algorithms can be achieved with various packages; the most popular are `algorithmic`, `algorithm2e`, `algorithmicx`, or `algpseudocode`. An overview is given at `https://tex.stackexchange.com/questions/229355`. An example of the use of the `alogrithm2e` package is given with Algorithm 9.1.

9.5 Bibliography

The referencing of prior work is a fundamental requirement of academic writing and well supported by LaTeX. The BibTeX reference management software is the most commonly used system for this purpose. Using the `\cite` command, it is possible to reference entries in a `.bib` file out of the text stream, e.g., as [Tur36]. The generation of the formatted bibliography needs a separate execution of `bibtex.exe` (see Table 9.2).

Algorithm 9.1: Gauss-Seidel

Input: A scalar ϵ, a matrix $\mathbf{A} = (a_{ij})$, a vector $\vec{b}$, and an initial vector $\vec{x}^{(0)}$
Output: $\vec{x}^{(n)}$ with $\mathbf{A}\vec{x}^{(n)} \approx \vec{b}$

for $k \leftarrow 1$ **to** *maximum iterations* **do**
  for $i \leftarrow 1$ **to** n **do**
    $x_i^{(k)} = \frac{1}{a_{ii}} \left(b_i - \sum_{j<i} a_{ij} x_j^{(k)} - \sum_{j>i} a_{ij} x_j^{(k-1)} \right)$;
  end
  if $|\vec{x}^{(k)} - \vec{x}^{(k-1)}| < \epsilon$ **then**
    break for;
  end
end
return $\vec{x}^{(k)}$;

9.6 Table of Contents

The table of contents is automatically built by successive runs of the compilation, e.g., of `pdflatex.exe`. The command `\setsecnumdepth` allows the specification of the depth of the table of contents and additional entries can be added to the table of contents using `\addcontentsline`. The starred versions of the sectioning commands, i.e., `\chapter*`, `\section*`, etc., remove the corresponding entry from the table of contents.

9.7 Acronyms / Glossary / Index

The list of acronyms, the glossary, and the index need to be built with a separate execution of `makeindex` (see Table 9.2). Acronyms have to be specified with `\newacronym` while glossary entries use `\newglossaryentry`. Both are then used in the document content with one of the variants of `\gls`, such as `\Gls`, `\glspl`, or `\Glspl`. Index items are simply generated by placing `\index{`⟨*entry*⟩`}` next to all the words that correspond to the index entry ⟨*entry*⟩. Note that many enhancements exist for these functionalities and the documentation of the `makeindex` and the `glossaries` packages should be consulted.

9.8 Tips

Since TeX and its successors do not employ a What You See Is What You Get (WYSIWYG) editing scheme, several guidelines improve the readability of the source content:

- Each sentence in the source text should start with a new line. This helps not only the user navigation through the text, but also enables revision control systems (e.g. Subversion (SVN), Git) to show the exact changes authored by different users. Paragraphs are separated by one (or more) empty lines.

- Environments, which are defined by a matching pair of `\begin{name}` and `\end{name}`, can be indented by whitespace to show their hierarchical structure.
- In most cases, the explicit use of whitespace (e.g. by adding `\hspace{4em}` or `\vspace{1.5cm}`) violates typographic guidelines and rules. Explicit formatting should only be employed as a last resort and, most likely, better ways to achieve the desired layout can be found by a quick web search.
- The use of bold or italic text is generally not supported by typographic considerations and the semantically meaningful `\emph{...}` should be used.

The predominant application of the LaTeX system is the generation of PDF files via the PdfLaTeX binaries. In the current version of PdfLaTeX, it is possible that absolute file paths and user account names are embedded in the final PDF document. While this poses only a minor security issue for all documents, it is highly problematic for double blind reviews. The process shown in Table 9.4 can be employed to strip all private information from the final PDF document.

	Command
1	Rename the PDF document `final.pdf` to `final.ps`.

2	Execute the following command:
	`ps2pdf -dPDFSETTINGS#/prepress ^`
	` -dCompatibilityLevel#1.4 ^`
	` -dAutoFilterColorImages#false ^`
	` -dAutoFilterGrayImages#false ^`
	` -dColorImageFilter#/FlateEncode ^`
	` -dGrayImageFilter#/FlateEncode ^`
	` -dMonoImageFilter#/FlateEncode ^`
	` -dDownsampleColorImages#false ^`
	` -dDownsampleGrayImages#false ^`
	` final.ps final.pdf`

On Unix-based systems, replace # with = and ^ with \.

Table 9.4: Anonymization of PDF documents.

9.9 Resources

9.9.1 Useful Links

In the following, a listing of useful web resources is given.

https://en.wikibooks.org/wiki/LaTeX An extensive wiki-based guide to LaTeX.

http://www.tex.ac.uk/faq A (huge) set of Frequently Asked Questions (FAQ) about TeX and LaTeX.

https://tex.stackexchange.com/ The definitive user forum for non-trivial LaTeX-related questions and answers.

9.9.2 Comprehensive TeX Archive Network (CTAN)

The CTAN is the official repository for all TeX related material. It can be accessed via `https://www.ctan.org/` and hosts (among other things) a huge variety of packages that provide extended functionality for TeX and its successors. Note that most packages contain PDF documentation that can be directly accessed via CTAN.

In the following, a short, non-exhaustive list of relevant CTAN-hosted packages is given together with their relative path.

algorithm2e Functionality for writing pseudo code.

amsmath Enhanced functionality for typesetting mathematical expressions.

amssymb Provides a multitude of mathematical symbols.

booktabs Improved typesetting of tables.

enumitem Control over the layout of lists (`itemize`, `enumerate`, `description`).

fontenc Determines font encoding of the output.

glossaries Create glossaries and list of acronyms.

graphicx Insert images into the document.

inputenc Determines encoding of the input.

l2tabu A description of bad practices when using LaTeX.

mathtools Further extension of mathematical typesetting.

memoir The document class on upon which the `vutinfth` document class is based.

multirow Allows table elements to span several rows.

pgfplots Function plot drawings.

pgf/TikZ Creating graphics inside LaTeX documents.

subcaption Allows the use of subfigures and enables their referencing.

symbols/comprehensive A listing of around 5000 symbols that can be used with LaTeX.

voss-mathmode A comprehensive overview of typesetting mathematics in LaTeX.

xcolor Allows the definition and use of colors.

List of Figures

1.1 Result of the proposed algorithm 4

9.1 The header logo at different sizes. 24

List of Tables

9.1 TEX/LATEX distributions for different operating systems. Recomended choice in **bold**. 21
9.2 Compilation steps for this document. The following abbreviations were used: table of contents (toc), list of figures (lof), list of tables (lot), list of algorithms (loa). 22
9.3 Adapted example from the LATEXguide at `https://en.wikibooks.org/wiki/LaTeX/Tables`. This example uses rules specific to the `booktabs` package and employs the multi-row functionality of the `multirow` package. 23
9.4 Anonymization of PDF documents. 26

List of Algorithms

9.1 Gauss-Seidel 25

Index

distribution, 21

Glossary

editor A text editor is a type of program used for editing plain text files.. 5

Acronyms

CTAN Comprehensive TeX Archive Network. 11

FAQ Frequently Asked Questions. 11

PDF Portable Document Format. 6, 10, 11

SVN Subversion. 10

WYSIWYG What You See Is What You Get. 9

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