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Enhancement of Footwear Impressions

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Rebeka Koszticsak, Bsc
Matrikelnummer 01325492

an der Fakultät für Informatik

der Technischen Universität Wien

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

Wien, 4. Jänner 2020

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

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

Vienna, 4th January, 2020

Rebeka Koszticsak   Robert Sablatnig

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Rebeka Koszticsak, Bsc
Address

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Danksagung

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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

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

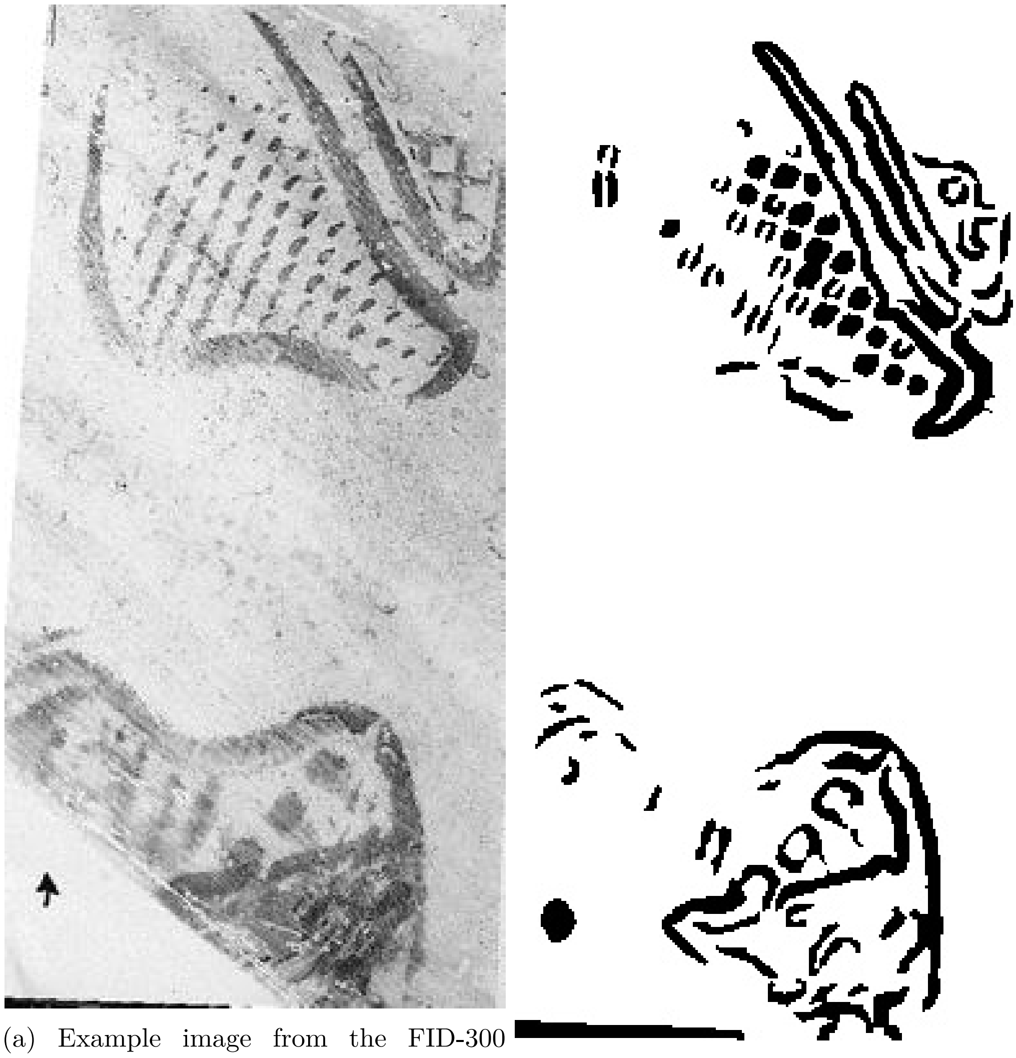
There are two main obsticles in the topic of shoeprint enhancement and in automatic shoeprint matching in general, the versitile image quality and appearance and the lack of universal and wide database. The shoeprint patterns are varying, there are approaches available which build models for given structures 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

In order to find and develop an effective algorithm for shoeprint enhancement an overview about relevant research has to be made first. Along the evident litrtiture of image enhancement other related topic such as discriminative image descriptors and feature classification are also considered, to gain the best insight possible and to be able to develop an algorithm which is optimized for the whole rest of the shoeprint identification pipeline. In this chapter the research on the domain of shoeprint identification is reviewed. Other than that publications from similar domains such as fingerprint and palmprint detection as well as tattoo identification are described. The related domains fingerprint identification and tatto recognition have been choosen for review because of their similar goal of edge structure and minimal image structure recognition. Moreover an overview of techniques from the field of natural image enhancement and description along with general image denoising is also given. This chapter is separated into four parts, first Image Enhancement techniques are described, after that algorithms developed for Noise Removal specifically are discussed. In the second half of the chapter proposed methods Image Descriptors and lastly for Featuree Classifications are reviewd

2.1 Image Enhancement

In this section image enhancement tecniques from four specific domains are discussed, these are shoe- and fingerprint identification, tattoo recognition and natural image enhancement.

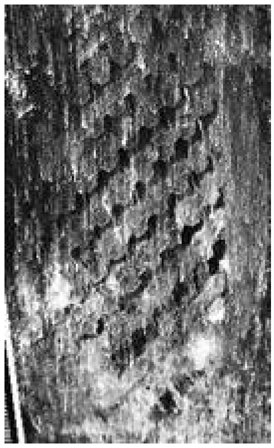
Shoeprint Enhnacement

There is an extensive research done in the field of enhancing shoeprint images. However, it has to be noticed that the problem definition and the use-case of the different publications varys. Becuse of the absence of standrad database, the discussed algorithms can be separated into two groups, techniques tested on synthetic samples and on real-life impressions. Synthetic samples are images scanned in images in a laboratorial enviroment for the purpose of building a dataset for shoeprint identification. The noise derives from scanning artifacts and computationally added distortions and modification. Furthermore many algorithms developed for real crime-scene data make restrictions about the input image and exclude noisy and poor quality images. Figure 2.1 shows example images from a synthetic 2.1a, from a restricted 2.1b and high 2.1c and low quality samples 2.1d from the FID-300 dataset. In the following discussion it is noticed repeatedly, which kind of dataset the proposed approach was tested on.

(a) Example image from a synthetic dataset

(b) Example image from a real crimescene dataset exluding low quality images

(c) Example high quality image from the FID-300 database



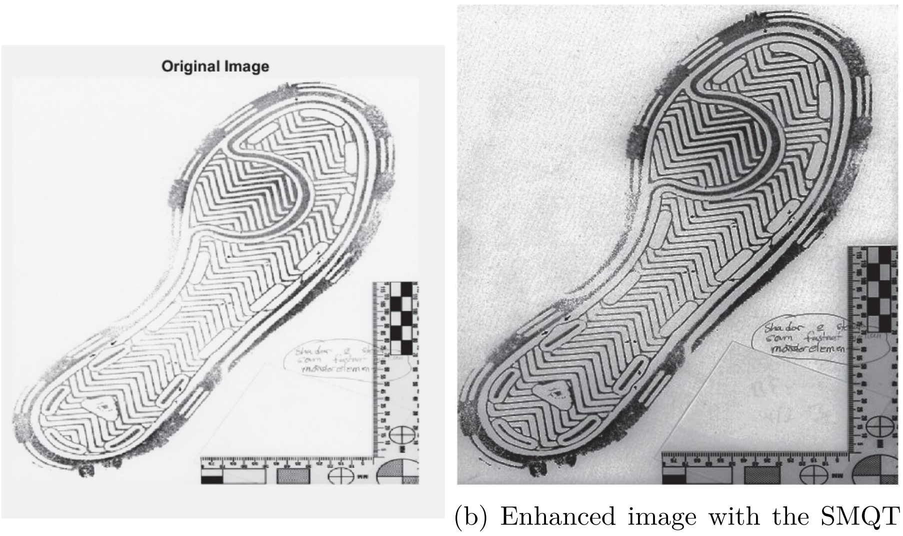
(d) Example low quality image from the FID-300 database

Figure 2.1: Example images of a synthetic [AK17], of a restricted [LWS14] and of the FID-300 [KAV14] dataset

Morphological Operations, Thresholding and Image Filtering are popular techniques for improve the quality of both kind, realistic and synthetic, of input data. Morphological operations, especially Opening and Closing, is used in many cases [WSYZ14], [KYZ14] , [LWS14], [TSKC10], [WWZ19], whereas Wang et al. [WSYZ14] uses a synthetic dataset, and other than Wu et al. [WWZ19] the forensic images are restricted to high quality data. Wang et al. [WSYZ14], Kong et al. [KYZ14] and Li et al. [LWS14] use the Morphological Operations to correct inconsistencies after thresholding. Similar to the previous approaches Wu et al. [WWZ19] applies the same pipeline on a real forensic dataset. Tang et al. [TSKC10] follow the same principle but instead of thresholding, after Canny edge detection is Opening and Closing used.

To create a binary image and eliminate noise various thresholding techniques are used. Otsu [WWZ19], [AH08], [AK17], [KYZ14] and adaptive thresholding [WSYZ14], [LWS14] are the two most popular algorithms. Algarni et al. [AH08] and Alizedah et al. [AK17] along with Wang et al. [WSYZ14] published their algorithms for synthetic datasets. Kong et al. [KYZ14] and Li et al. [LWS14] tested on restricted, whereas Wu et al. [WWZ19] developed their approach for full real forensic database. Wang et al. [WSYZ14] and Wu et al. [WWZ19] combine thresholding with a grid based approach to calculate exact thresholds for every subarea of the picture.

An other way to eliminate noise is image filtering. Alizadeh et al. [AK17] uses a simple Median filter on a synthetic dataset. Zhang et al. [ZA05] test on synthetic database as well. They take advantage on the partial different equations approach. In this way the edges are preserved while the background is smoothed according to a controlled curvature motion criteria. Katireddy et al. [KS17] uses Successive Mean Quantization Transfrom (SMQT) [Nil13] as an only step to ehnace a real-life database. Figure 2.2 shows the output of the SMQT algorithm on an example image.



(a) Example shoeprint impression

(b) Enhanced image with the SMQT algorithm

Figure 2.2: Example image about the enhancement feature of the SMQT algorithm [KS17]

Bandpass operators are also used for noise supression. The images are converted to the frequency domain where high and low frequencies are eliminated. Gueham et al. [?] and Richetelli et al. [RLL$^+$17] utilize this method on a synthetic database. Li et al. [LWS14] work with a restricted real dataset, where only the lower frequencies are eliminated.

Fingerprint Enhnacement

Bandpass and general image filtering is popular in the field of fingerprint enhancement as well. Zhou et al. [ZSL+11] uses a low- and a highpass filter to eliminate striking frequencies. Wang et al. [WLWL14] decompose the image into four subbands and process them separately, calculating the noise for every subband respectively. Li et al. [LFLY12] use Fourier transformation combined with Scale Invariant Feature Transform (SIFT) to enhance the fingerrint images. With SIFT the intresting points in the Fourier domain are found and secured, while the image is filtered to suppress noise and other inconsistencies. Jahan et al. [JCI17] apply Fuzzy filtering followed by thinning. Fuzzy filter is a local method to preserve the edge information and fine lines structures and supress the noisy background of the input.

reference

Tattoo Enhnacement

For tattoo enhancement an algorithm from Han et al. [HJ13] was proposed which combines Gaussian filtering with Hysteresis thresholding. Hysteresis thresholding is a neighborhood-aware approach where a pixel is labelled when it is above a given low threshold and simultaneously connected to other pixels meeting a higher thresholding criteria. Acton et al. [AR08] propose to use an Active Contour Model to find the boundaries of tattoo images and apply Opening and Closing as well to get rid of small inconsistencies.

reference

reference

Natural Image Enhnacement

Along Signal, especially Bandpass, general Image Filtering and Thresholding Histogram and Color Operations are also common for natural image enhancement. Maini et al. [MA10] published a review about natural image enhancing algorithms and defined two main groups of algorithms, Frequency and Spatial Domain Methods. First publications utilizing techniques from the first group are discussed, after that the usage of Spatial Domain Methods is reviewed.

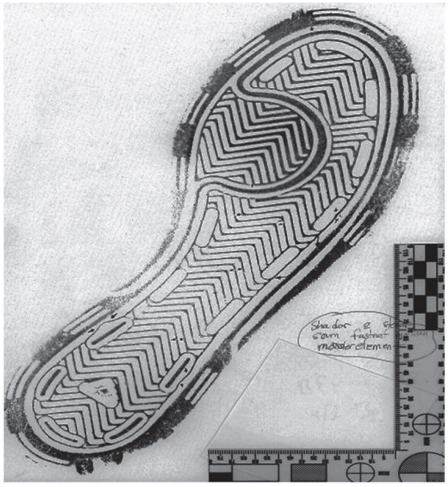
Xu et al. [XWYH16] combines Bandpass filtering with adaptive thresholding. Similar to Wang et al. [WLWL14] the image is separated into four subbands, and the threshold is calculated for every image separately. Sugamya et al. [SPV16] applies Subband Decomposition with two staged Histogram Equalization. The histogram of the input is equalized gloablly first, after that it is decomposed into subbands to Equalize the values locally for every four generated subimage.

Median Fiters are used for noise suppression no only in the domain of shoeprint enhancement [AK17] but also for natural image processing. Apart from Median Filter Li et al. [LLGF14] utilize Average and Wiener Filter as well to suppress the occuring noise and to prepare the input for neighborhood based feature extraction. Feng et al.

[FJZY11] proposed a Bag-of-Words algorithm based on the Gabor wavelets of the input. For preprocessing the Watershed Transform is used.

Histogram Operations can be combined with not only Bandpass filtering as Sugamya et al. [SPV16] do but also with Thresholding as proposed by Yao et al. [YZL$^+$16]. Their aprroach separates the histogram of the input into two parts according to Otsuś method. After that the histogram is equalized of the generated subimages. Figure 2.3 shows the results of algorithm on an example image.

(a) Example low-contrast image



(b) Enhanced image with the histogram thresholding algorithm

Figure 2.3: Example image [YZL$^+$16] about the enhancement feature of the algorithm proposed by Yao et al. [YZL$^+$16]

Color processing techniques are widespresd in he topic of natural image enhancement. It can be used for image dehazing, so for low contrast images, [SK18] and also for classical noise removal [RLCL18], [ZSP$^+$16]. Bhairannawar et al. [BPJH17] switch from RGB to HSV and use Laplace filter to detect regions with intensity changes. During processing the H chanel is not modified to prevent color distortion artifacts. Althoug color processing is a well researched field with many promissing solutions, no wider overview is given in this thesis. There are shoeprint impression datasets with colored samples, FID-300 provides grayscale images thus no color processing approach can be used in this specific case.

2.2 Noise Removal

Noise Removal methods are based on estimating the original image, and based on that eliminating the deviating features of the data. One way is denoising through gradient histogram preservation [ZZSZ13]. The distribution of gradients is estimated on the original image, and the noisy image is adjusted to the calculated values. An alternative way is to decompose a single image and based on the clear parts the noisy regions are approximated. Huang et al. [HKWL13] propose a self-learning algorithm, which only consideres the high frequency parts of the decomposed image. There were several approaches published, where the images is separated is separated spatially instead of in the frequncy domain. [XZZ+15], [TM13], [CM11] and [GZZL15] are tecniques based on the idea of non-local means, where the image is subsampled into tiles and the pixels are set to the mean of regions belongng to the same cluster. The main difference between the previous algorithms is how they classify the image subregions into different classes. Taleby et al. [TM13] uses an iterative shrinkage strategy. Chatterjee et al. [CM11] groups the geometrically similar regions and estimate the noise for every class separately with a Wiener Filter. Whereas Guo et al. [GZZL15] utilize Block Matching to determine the cluster memberships. Additionally the spatial location is also considered while calculating the mean value in a given class. The members are weighted according to the distance to the current region.

2.3 Image Description

Similar to the previous Image Enhancement section 2.1 this part is also subdivided into four domains offering solutions for the same problem in different domains. In this section the published image features are described which are proposed to be the most discriminative for their field. Shoeprint descriptors are described first, after that fingerprint features are discussed. Following that an overview about tattoo and natural image descriptors is given at the end.

Shoeprint Descriptors

In the research of Shoeprint Identification and more exactly Shoeprint Description the varying difficulty and quality of the different datasets is a continuous issue, therofore the properties of the database the given approach was tested in is noted repeatedly. Signal or frequency domain based image features are popular in both groups of algorithms using synthetic or real samples for testing.

Fingerprint Descriptors

Tattoo Descriptors

Natural Image Descriptors

2.4 Classification

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

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