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DEPARTMENT OF INTELLIGENT SYSTEMS
ÚSTAV INTELIGENTNÍCH SYSTÉMŮ

DETECTION AND LOCALIZATION OF SKIN DISEASES IN FINGERPRINTS

DETEKCE A LOKALIZACE KOŽNÍCH ONEMOCNĚNÍ U OTISKU PRSTU

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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Bachelor's Thesis Specification

22498

Student: **Vasiljević Nemanja**
Programme: Information Technology
Title: **Partial Fingerprint Detection Using Blob Detection Algorithm**
Category: Image Processing

Assignment:

1. Study biometric literature in particular fingerprints and learn about influence of skin diseases in fingerprint recognition.
2. Design of an algorithm for detection and localization of skin diseases in fingerprints.
3. Implement the proposed algorithms from the previous steps.
4. Test the experiments and algorithms on a database (the database is available on STRaDe server) of fingerprints influenced by skin diseases.
5. Discuss about the results, and check whether results lived up to expectations.

Recommended literature:

- Maltoni, D., Maio, D., Jain, A.K. and Prabhakar, S.: *Handbook of Fingerprint Recognition*. Springer, 2009, pages 512. ISBN 978-1-8488-2254-2.

Detailed formal requirements can be found at http://www.fit.vutbr.cz/info/szz/

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Abstract

This bachelor thesis discusses detection and localization of skin diseases in damaged fingerprint images and describes the solution implemented using image processing techniques.

Abstrakt

Tato bakalářská práce se zabyva problemetikou detekci a lokalizaci kožních onemocnění v poškozených snímcích otisků prstů a popisuje řešení realizované pomocí technik zpracování obrazu.

Keywords

Image processing, biometrics, skin diseases, fingerprint recognition, OpenCV, blob detection algorithm

Klíčová slova

Zpracovaní obrazu, biometrie, kožní onemocnění, rozpoznávání otisků prstů, OpenCV, blob detekční algoritmus

Reference

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Rozšířený abstrakt

Hlavním cílem této bakalářské práce bylo naprogramovat aplikaci, která detekuje až 3 různá onemocnění otisku prstu. Výsledný program se skládá ze 3 částí. První část se zabývá analýzou obrazu otisku, 2. část se věnuje detekci konkretního onemocnění a poslední část implementuje grafické uživatelské rozhraní. Aplikace také vizuálně zvýrazní poškozené části otisku na obrázku a určí procento poškození.

Aplikace nejdříve provede analýzu vstupního obrázku otisku prstu. Z původního obrazu se vytvoří 3 mezivýsledky, které jsou potom použity v detekci onemocnění a také se vytvoří mapa poškozených bloků. Analýza se provede ve 3 krocích: předzpracování, nalezení poškozených částí otisku a analýza papilárních linií. V průběhu předzpracování, původní obraz se transformuje do podoby, která umožňuje nejednoduší detekci onemocnění. Analýza papilárních linií převede obraz na mapu bloků a následně nalezené všechny poškozené bloky.

Po analýze se provede detekce onemocnění, která je implementovaná pomocí 3 algoritmů: detekce bílých bodů, detekce linií a detekce tzv. gepardových skvrn. Každý algoritmus je založen na blob algoritmu. Výsledkem této části je informace o přítomnost konkretního onemocnění na otisku.

Aplikace se ovládá grafickým uživatelským rozhraním. Rozhraní nabízí 2 módy operace. První je detailní mód, který provede analýzu a detekci nad 1 obrázkem otisku. Aplikace ukáže všechny korky vedoucí k výsledku analýzy. Uživatel může uložit výsledky. 2. mód provádí analýzu nad celým adresářem obsahující obrázky otisků prstů. Výsledkem 2. módu je statistika o každém detekovaném onemocnění.

Aplikace je implementovaná v jazyce C++. GUI je implementován pomocí knihovny Qt a funkce pracující z obrázky pomocí knihovny OpenCV.

Testování bylo provedeno na sadě otisků které byly poskytnuty ze strany výzkumné skupiny STRaDe. Výsledky považuji za velmi úspěšné. Onemocnění akrodermatitida bylo detekováno s přesnosti 95,3 %, atopický ekzém s přesnosti 61.3 % a bradavice s přesnosti 77.2 %.

Detection and Localization of Skin Diseases in Fingerprints

Declaration

Hereby I declare that this bachelor's thesis was prepared as an original author's work under the supervision of Mrs. Mona Heidari. All the relevant information sources, which were used during preparation of this thesis, are properly cited and included in the list of references.

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Nemanja Vasiljević
July 31, 2019

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I would like to thank my supervisor, Ing. Mona Heidari, for the guidance, support and encouragement she has provided during my research and writing this thesis.

Contents

Chapter 1

Introduction

With advance of technology our society became more electronically connected and more mobile, therefore security became one of the most important things today. It was needed for improving methods for determining person's identity. Establishing person's identity using methods such as PIN, passwords and cards are not enough reliable. PIN and password can be forgotten, shared or in some cases can be guessed, cards can be lost, etc. Therefore biometric identifiers became more popular. The main reason why biometric identifiers became so much popular it's because they are consider more reliable for person identification. It's very hard to forge or misplace biometric identifiers, and some of them are unique for every person. Fingerprints are the most popular biometric identifier today, they are unique and remains unchanged.

There isn't two people that have exactly the same fingerprints. Even identical twins, with identical DNA, will have different fingerprints. Fingerprints remain almost unchanged through whole lifespan and therefore are one of the most reliable methods for person recognition. These unique properties allow fingerprints to be used in all sorts of ways, including for biometric security, background checks, mass disaster identification, and in criminal situations.Although that using fingerprints as primary way for person identification is very efficient, it has their own disadvantages.

People who suffered from some kind of skin disease, that affected fingertip skin, may have also their fingerprint pattern affected and damaged. Skins diseases only affecting the color of skin almost don't have impact on quality of resulting fingerprint image. But if skin disease affects and changes structure of papillary line, its often impossible to determine original structure of papillary lines and it's impossible to decide if claimed identity is the user's identity. In this case user is restricted by not being able to use fingerprint recognition system, even if his fingers don't have any symptoms of skin disease anymore [7]. Persons that were affected by these types of diseases are in disadvantages and can't use fingerprint recognition system. The goal of this thesis is to contribute improving algorithms for detecting skin diseases that attack structure of papillary line and their localization. Chapter

2 gives introduction to basic biometrics while chapter 3 describes concept of live-scan and different sensing technology. Chapter 4 describes skin structure and chapter 5 introduces different skin diseases that are subject of this thesis.

Chapter 2

Biometrics

2.1 Introduction to Biometrics

In the early days of civilization, people lived in small communities where they could easily recognize each other. However, an explosion in population and increasing mobility in modern society required the development of identity management systems that are capable of efficient record, maintain and obliterate person identities. Biometric recognition, or simply biometrics, offers more reliable way for person precognition. Since biometric identifiers are more connected to an individual, therefore it is harder to manipulate, share or forget them. Biometric traits represent a strong relationship between a person and his identity. The most commonly used biometric identifiers are: face, fingerprint, had geometry, had/finger vein, iris, signature and voice. Biometric systems measure one or more biometric identifiers of an individual to determinate or verify his identity. Process of collecting biometrics identifiers, their extraction, template creation and storing in database, is called enrollment process. Depending on the application context, biometric systems can be called either a verification system or identification system[6].

2.2 Verification systems

Verification systems are used for authenticating person's identity by comparing the captured biometric identifiers with her previously enrolled biometric template in the system. Verification systems are based on 1:1 comparison and their goal is to confirm whether claim identity is true. Verification systems are more accurate than identification systems, even when sized of database increases [13][6].

2.3 Identification systems

Identification systems seek to identify an unknown person, or unknown biometric. Captured biometric identifiers are compared with every enrolled template in database until they match. Identification systems are described as a one-to-many matching system, where n represents the total number of biometrics in database [13][6].

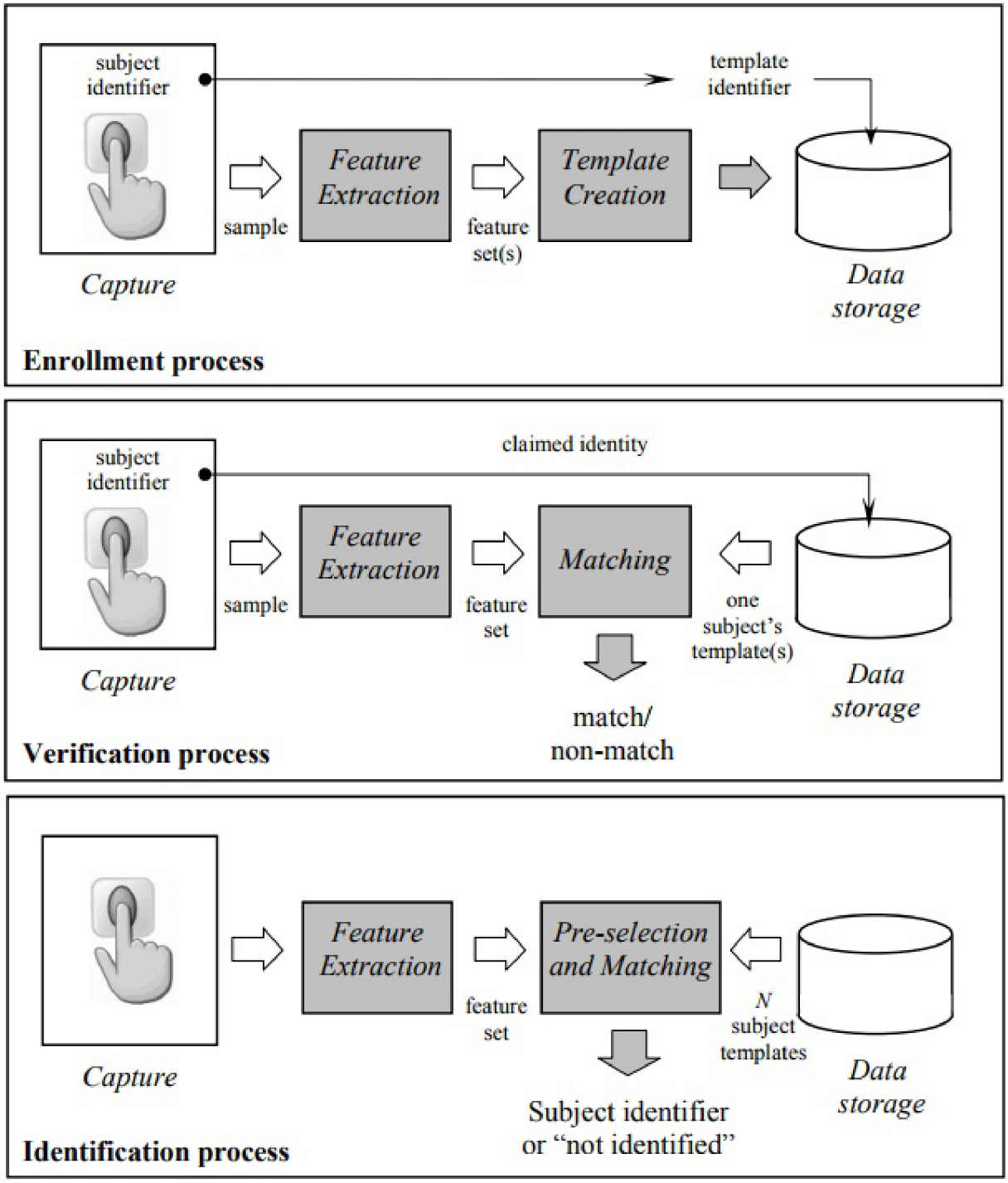

Figure 2.1: Biometric systems. Source: [6]

Chapter 3

Live-Scan Fingerprint Sensing

Live-scan fingerprinting is technique and technology used by law enforcement or private facilities to capture fingerprints electronically, without using some traditional methods like ink and paper. The most important part of a live-scan fingerprint scanner is the sensor (or sensing element), which is the component where the fingerprint image is formed. These scanners can be divided into several groups upon their sensing technology.

3.1 Capacitive fingerprint scanners

Fingerprint scanners based on a capacitive sensing technology are also very common type of fingerprint scanners. The sensor itself is a two-dimensional array of conductive plates. Small electrical charges are created between the surface of the finger and each of the silicon plates when a finger is placed on the chip. By measuring that electrical charges, it is possible to reconstruct the profile of papillary lines ridges and valleys and thus to reconstruct the fingerprint image. This type of sensors cannot be easily deceived by presentation of photography or printed image of fingerprint because they measure distance and therefore three-dimensional surface is needed [6].

3.2 Thermal fingerprint scanners

Thermal sensors are built from pyro-electric material that produces current based on temperature difference. After putting finger on sensor, fingerprint ridges produce a different temperature then the valleys. Therefore it is possible to acquire fingerprint's image [6].

3.3 Electric field fingerprint scanners

Main advantage of electric field sensors is that they are able to acquire a high quality fingerprint image under the surface of skin. This advantage can be used in cases where skin has suffered from some disease. Scanners are based on emitting a radio frequency sinusoidal signal and on matrix of antennas that receives a small signal that is modulated by surface of skin. That signals represent the electric field in subsurface of finger skin and by measuring it is able to acquire fingerprint image [6].

3.4 Piezoelectric fingerprint scanners

This type of scanners is based on pressure-sensitive sensors. After mechanical stress is applied to sensor, they produce an electrical signal. Since ridges and valleys are present at different distances from the sensor surface, sensor will produce different current for ridges and valleys. Unfortunately, these sensors are not able to detect all difference between ridges and valleys and resulting image can be blurred [6].

3.5 Piezoelectric fingerprint scanners

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3.6 Ultrasound fingerprint scanners

The ultrasound sensors are based on sending acoustic signal toward finger surface and capturing their echo. Sensor has two main components: first is transmitter, used for sending acoustic signals, and receiver, used for receiving echo signals. Ultrasound sensors acquire fingerprint image from subsurface of finger skin and therefore resulting image are not effected by dirt or oil accumulations on finger. This type of scanners, are very expensive and acquiring image takes couple minutes, therefore they are not globaly represented [6] [12].

Chapter 4

Skin structure

The skin is largest organ in human body, comprising about 15% of the body weight. In terms of chemical composition the skin is 2% lipids, 25% protein and 70% water. Each square centimeter of skin has 6 million cells, 5,000 sensory points, 100 sweat glands and 15 sebaceous glands. The skin is divided in three layers: epidermis (the outer layer), dermis and subcutaneous (fat) layer [12][9].

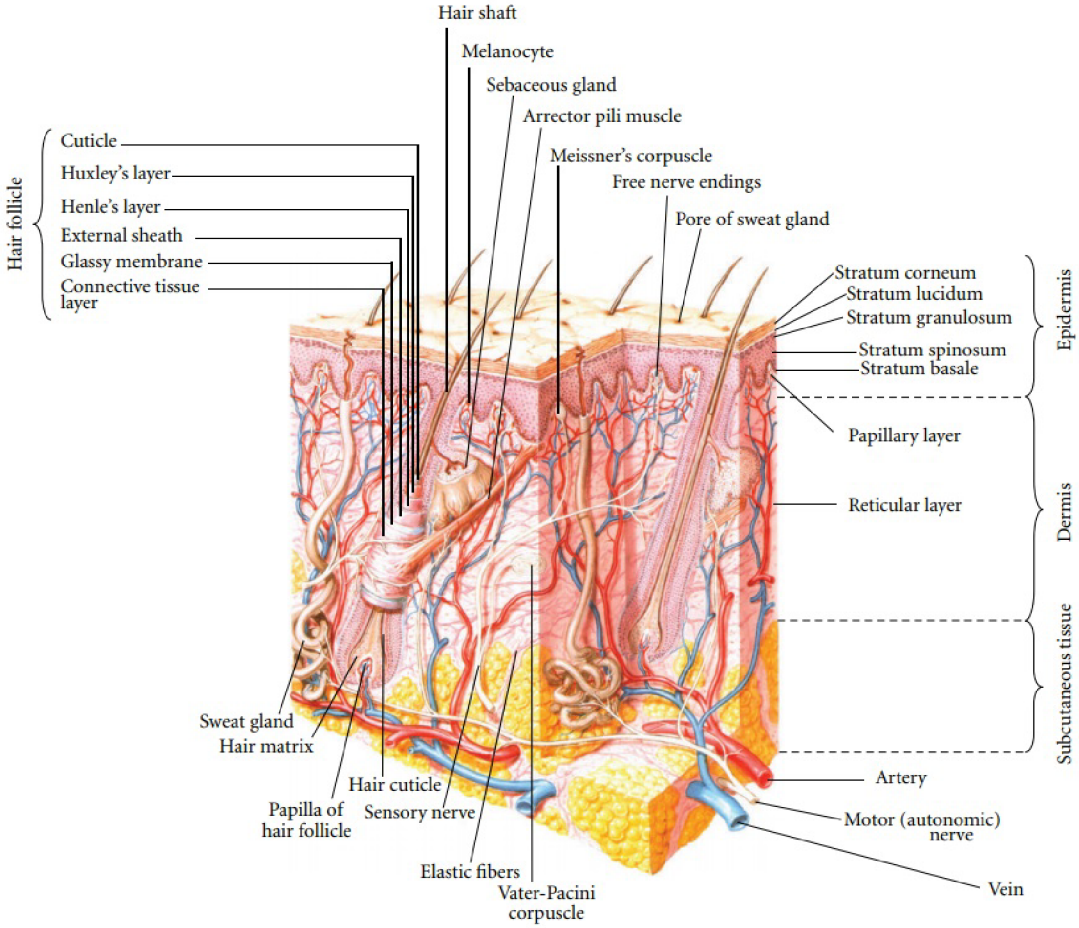

Figure 4.1: Skin structure. Source: [14]

4.1 The Epidermis

The epidermis is the top most layer of the skin. This layer has no blood supply, but it is nourished by the blood vessel in the dermis. Two important groups of cells are located in this layer. First group is Keatinocytes. Their lifespan begins in lowermost portion of epidermis, as they mature, they move upwards and eventually at the end of their life cycle, they reach uppermost layer of the epidermis. This cells makes the skin waterproof and tough. Another significant group of cells in the epidermis are melanocytes. Melanocytes produce melanin, the pigment responsible for skin tone and color. Melanin protects skin from strong sunlight and is able to dissipate over 99% of absorbed UV radiation. Melanin also determinate skin color, more melanin means that person will have darker skin [10].

4.2 The Dermis

The dermis is the middle layer of skin and it is the thickest skin layer. The dermis contains tiny blood vessels (capillaries) that carry oxygen and nutrients. This layer is involved in regulation of the body temperature [10].

4.3 The Subcutaneous

Subcutaneous tissue is the innermost layer of the skin located under the dermis consisting of connective tissue and fat molecules. This layer protects the bones, muscles and organs under the skin from psysical damage. Additionally, the subcutaneous acts as heat insulator protecting underlying tissues from cold and overheating [10].

4.4 The life cyrcle of skin

Skin is constantly being regenerated [5]. A skin cell starts its life at the lower layer of the skin (the basal layer of the dermis), which is supplied with blood vessels and nerve endings. The cell migrates upward for about two weeks until it reaches the bottom portion of the epidermis, which is the outermost skin layer. The epidermis is not supplied with blood vessels but has nerve endings. For another 2 weeks, the cell undergoes a series of changes in the epidermis, gradually flattening out and moving toward the surface. Then it dies and is shed.
There are six skin functions [5] as follows:

- ***Sensation*** — The nerve endings in the skin detect touch, heat, cold, pain, and light pressure.
- ***Heat Regulation*** — Skin helps to regulate the body temperature by sweating to cool the body down when it overheats and by shivering creating “goose bumps” when it is cold. Shivering closes the pores. The tiny hair that stands on end traps warm air and thus helps keep the body warm.
- ***Absorption*** — Absorption of ultraviolet rays from the sun helps to form vitamin D in the body, which is vital for bone formation. Some creams, essential oils, and medicines (e.g., antismoking patches) can also be absorbed through the skin into the blood stream.

- ***Protection*** — The skin protects the body from ultraviolet light—too much of it is harmful to the body—by producing a pigment called melanin. It also protects us from the invasion of bacteria and germs by forming an acid mantle (formed by the skin sebum and sweat). This barrier also prevents moisture loss.
- ***Excretion*** — Waste products and toxins are eliminated from the body through the sweat glands. It is a very important function which helps to keep the body "clean" from the inside.
- ***Secretion*** — Sebum and sweat are secreted onto the skin surface. The sebum keeps the skin lubricated and soft, and the sweat combines with the sebum to form an acid mantle which creates the right pH balance for the skin to fight off infection.

Chapter 5

Skin diseases

5.1 Atopic eczema

Atopic eczema causes the skin to become red, swollen, itchy and cracked. The skin became thickened and cracked, which results in exposition of red to brownish-gray patches. In base case atopic eczema results only with small patches of dry skin but in others atopic eczema may results in widespread red, inflamed skin all over the body. Atopic eczema can affect any part of the body, but in most cases affects the hands [4].

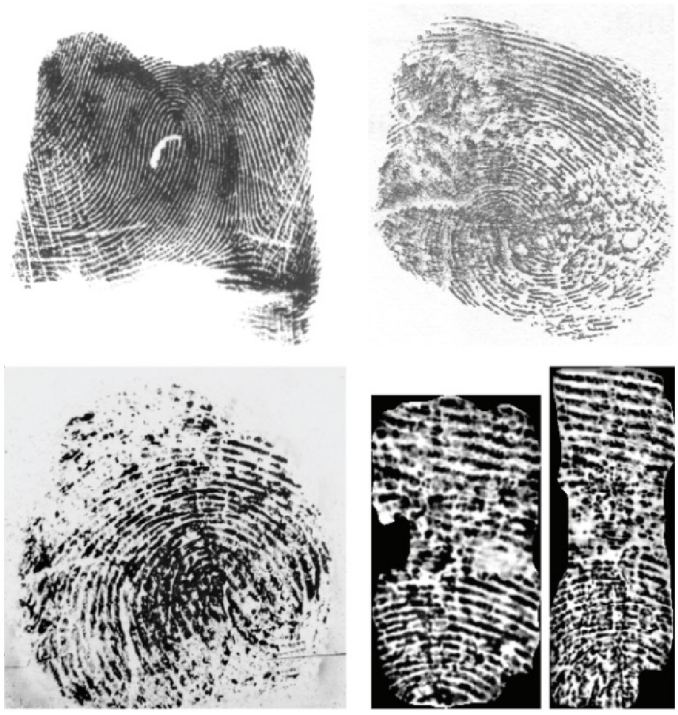

Figure 5.1: Atopic eczema(same person). Source:[8]

5.2 Dyshidrotic eczema (Pompholyx)

Pompholyx is characterized by sudden eruptions of usually highly pruritic, symmetric vesicles on the palms, lateral fingers or plantar feet. Hads-alone involvement occurs in 80%. The acute process involves initial vesiculation, with is usually marked on the palms and lateral aspects of the fingers. The process ends with peeling sometimes leaving a cracked red base. It is one of the most common skin disorders. It is not related to blockage of sweat ducts, although palmoplantar hyperhidrosis is common in these patients. Itching precedes the appearance of tiny water-filled vesicles on the palms and sides of the fingers which are relatively deep seated. The skin may be red and wet. The vesicles slowly resolve and are replaced by erythematous scaly patches. Chronic eczematous changes with erythema, scaling, and lichenification may follow [8].

Figure 5.2: Dyshidrotic eczema (same person). Source: database

5.3 Hyperkeratotic eczema

Hyperkeratotic eczema is a condition which happens on the hands and/or feet palm. It is a well-known yet a complicated entity that is usually chronic and difficult to be cured by therapy. The visible signs are represented by dry, thick, gray plaques implicating the palmar and/or plantar surfaces [3].

Figure 5.3: Hyperkeratotic eczema (same person). Source: database

5.4 Verruca vulgaris (warts)

Warts (verruca vulgaris) [10] are extremely common benign epidermal neoplasms that are caused by human papilloma viruses (HPVs). Warts commonly appear at sites of trauma, on the hand, in periungual regions. HPVs induce hyperplasia and hyperkeratosis. Large widespread warts occur in immunodeficient patients as well in patients with atopic eczema. The aggressive surgical therapy may result in scarring. The lesions can affect all fingers of both hands [8] .

Figure 5.4: Verruca vulgaris (same person). Source: [8]

Chapter 6

Application design

The main task of this thesis was to develop an application which is capable of detecting 3 different skin diseases causing the damage of fingerprints. Final application consists of 3 major parts, the first is responsible for analyzing fingerprint images(image preprocessing, damage extraction), the second one is responsible of detecting the disease and the final part provides graphical user interface.
This chapter describes the design and functionality of the application.

6.1 Application goals

The main object of the resulting application is the implementation of diseases detection algorithm, which will provide results on the sample of fingerprint scans with very high accuracy. The primary function of resulting application is ability to classify images based on extracted features after analyzing them. Output of the application is a report of the disease which most likely caused the damage on the fingerprint for every analyzed image.

Apart from main goal, application contains several sub-goals that logically connected with main goal which are:

- Ability to determinate healthy and damaged parts of the fingerprint
- Ability to determinate if a fingerprint is damaged at all, that is to determinate percentage of damaged area and probability of fingerprint reconstruction.
- Ability to visualize the whole detection process.

These goals are achieved by creating a GUI application that whose three main building blocks are going to be discussed in the following section

6.2 Application design overview

Image analysis and disease detection both play significant role in the final product of this thesis.

The task of this image analysis is to process the input image of a fingerprint and create intermediary picture for every of the 3 diseases that could be detected by this application. These intermediary pictures are later used to detect possible diseases. Besides

this task, image analysis process also creates a map of possible damaged blocks, which is used for filtering detected defects and for computing percent of damaged area in fingerprint.

The disease detection process of the highly depends on the number and types of extracted image features provided by image analysis. The main task of this component is to detect defected areas in fingerprint that have similar characteristics as some of the 3 diseases. After detection process the damaged areas are highlighted on the original fingerprint image.

6.2.1 Image Analyzer Design

Since this component has several tasks, the design is divided in three important parts: preprocessing, damaged area extractor and papillary lines analyzer.

The preprocessing is responsible for changing input image to the point which allows the best possible detection. This means that fingerprint image undergoes several different changes that have a goal to remove noise and to transfer colors from shades of gray to only black and white color. The preprocessing is also responsible for detection of fingerprint area, i.e removal of background.

The papillary lines analyzer is based on Orientation field algorithm and transforms input image into a map of blocks, where for every block determines if it is damaged. This map is later used to deterimanate the percent of damage in fingerprint and to determinate healthy and damaged parts of the fingerprint.

Damaged Area Extractor is process which takes preprocessed fingerprint picture and extracts white areas in fingerprint that represent defects with very high probability. The main goal of this component is to detect ubnormal white areas in fingerprint image. This means that Damaged Area Extractor designed in way to detected white areas that are not usual spaces between papillary lines. Output of this component is used by disease detection process.

6.2.2 Disease Detection Process

Since there is wide range of possible types of damages that could occur in fingerprint image, this process is done by several sub-detectors, for different types of damage:

- White spots detector
- Straight lines detector
- Cheetah-spots detector

Each of them is based on blob detection algorithm with different parameters for every type of damage. The Detector's output is information if some of the diseases is detected and the area of fingerprint where disease was detected.

6.2.3 Data flow

From design view, it is important to determinate the inputs and outputs of particular classes and describe the data flow of the application.

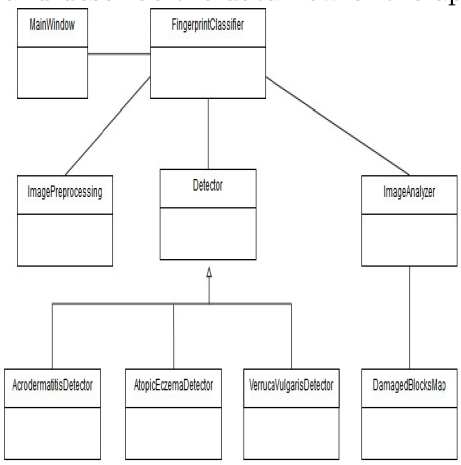

Figure 6.1: Simplified application class design.

A fingerprint image and other configurations is given by user throught GUI and is stored in Config object. Image is then processed using Pipeline object and based on output data, such as names od detected diseases, estimated percentage of damaged fingerprint area and estimated damaged / healthy areas. Apart of acting like pipeline, this object has one major task. Classifier determinates detected diseases based on given rules and output of blob detection.

ImagePreprocessing object does different types of filtering on input image, in order to remove noise and transoform input image to only black-white image. This object has one more important task, which is detection of background in image. Result of this tasks allows other components to ignore background and improve their results.

ImageAnalyzer object analyzes input image. The whole process is based on Orientation Field algorithm and the result of this process is the map of possible damaged areas in fingerprint image. The detectors requires a normalized fingerprint image as an input and output of this process is later used to determinate healthy/damaged areas in fingeprint and percentage od damage.

DamagedAreaExtractor (DAE) object takes preprocessed input image and, based on his unique algorithm, extracts white areas in fingerprint that are highly likely to be damaged areas. Outputs of this object are two images, first image is used for detection of eczema and focuses on even small damages, where second images is used for Verruca Vulgaris detection and is focused only on bigger damages.

DiseaseDetector object is devided on 3 sub-detectors (for each detecting disease). Each sub-detector takes one input image and configuration that was given by user. DiseaseDetector starts detecting disease using blob detection algorithm and visualizes detected diseases on resulting image.

Config object - beside storing all configuration given by user, this Singelton stores

every important steps of detection. Steps are grouped by processes (Preprocessing, Orientation field, Blob Detection, etc)

StateMap object takes results from Orientation field, DAE and Disease detector, and for each input creates map with damaged/healthy areas in fingerprint. After that maps are combined into one resulting map, which represents combination of 3 algorithms. Based on resulting map, this object is capable to determinate precentage of damaged area in fingerprint image.

6.2.4 Graphic User Interface and Application Usage

The application was designed with graphical user interface that allows the user to load fingerprint image and to select path where step images will be stored. In case that user does not select output path, given steps will not be saved.

The button **„Set Params“** opens new windows containing current configuration for disease detection. User can freely change parameters for used algorithms(Orientation field, StateMap, Disease detection for each disease). There is also options for user to reset configuration and return it to default.

The button **„Run“** starts the process and new tab with result is created. Tab contains important information about detection, like name of detected diseases and percentage of damaged area in fingerprint. Main part of result tab is reserved for visualizing detected diseases features in image. Steps of diseases detection are grouped by processes and user can manually choose one of given processes: *Preprocessing*, *Orientation field*, *Detection for acrodermatitis*, *Detection for eczema*, *Detection for Verruca Vulgaris* and *State map*. Buttons *Pervious* and *Next* allows user to change step in given process. Each step is visualized with image and has it’s own description.

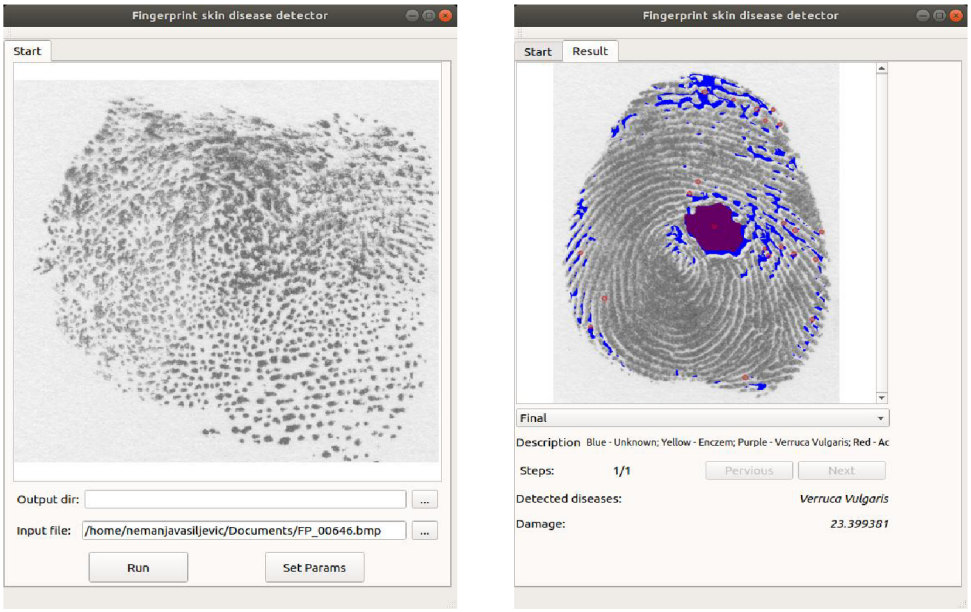

Figure 6.2: GUI - input

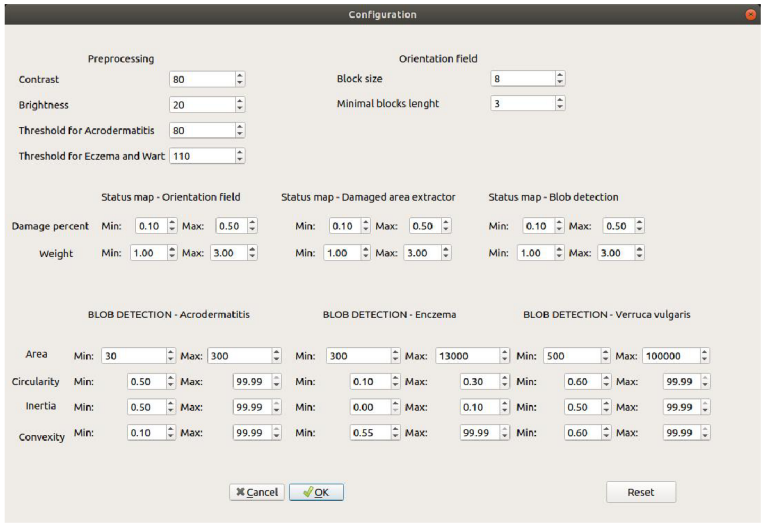

Figure 6.3: GUI - Set params

Chapter 7

Implementation

The application was developed using programming language C++, framework QT (version 5.9 under LGPL licence) for graphic user interface and using Open Source Computer Vision library (OpenCV, version 4.1.0 under BSD license).
In this chapter, the specific algorithms used to create this application will be described and their advantages and disadvantages will be discussed, alongside with it some of the core functions that are essential for program functionality and data structures that were used for storing through this process will be explained and described.

7.1 Image preprocessing

The first step after loading input image is image preprocessing, which transoforms it in a way that allows the application to work with whole fingerprint. It would be unnecessary to load image in BGR format because whole program works and relies on only white and black color. Therefore image is loaded in grayscale format.

Next step was to brush and highlight papillary lines. That was achieved by increasing contrast and brightness of image. In this step papillary lines which are represented with lower intensity (effect of unequal scanning of all parts of fingerprint) are highlighted.

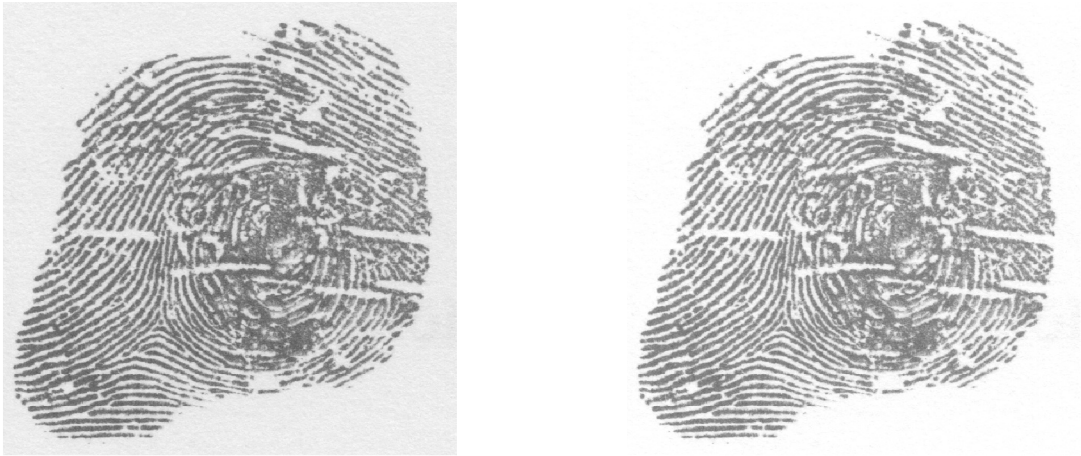

Figure 7.1: left - input picture, right - image increasing contrast and brightness

Next step was **histogram equalization**. Histogram is statistic representation of the tonal distribution in a digital image. Example of histogram distribution is shown in figure 7.2. Horizontal axis represents individual intensity and vertical axis represents pixels count with corresponding intensity. In this histogram we can see, that individual intensity are not represented equally and some of them are not represented at all. Histogram equalization [1234] is a spatial domain method that produces output image with uniform distribution of pixel intensity means that the histogram of the output image is flattened and extended systematically. Resultant histogram is shown in figure 7.2.

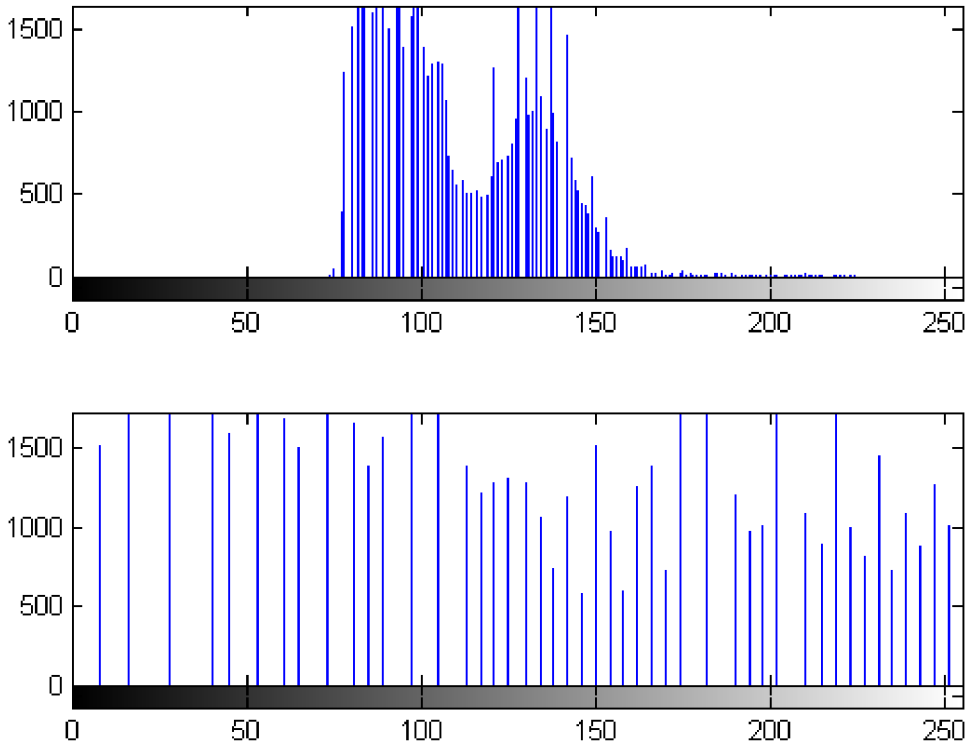

Figure 7.2: Histogram graph

Applying this method quality of image will be increased and lower illuminated areas will be highlighted. This step allows parts of fingerprint that are less imprinted to be also used. Histogram equalization was implemented using function **cv::equalizeHist()** from library OpenCV. The figure 7.3 shows an image before and after histogram equalization. It is obvious how parts with lower illumination were highlighted and distinguished from background.

Smoothing is often used to reduce noise within image and prepare the image for segmentation. Most of smoothing methods are based on low pass filters and for implementation of this application *Gaussian low pass filter* was used.

Figure 7.3: Left - fingerprint before and after using histogram equalization.

Figure 7.4: Left - fingerprint before and after using gaussian blur filter.

The next part of image preprocessing is converting result image to binary image. This was implemented using method called **thresholding**. Global thresholding is the simplest type of thresholding. For every pixel in image following equation it is true:

Major problem in global trhesholding is determination of ideal value for thresh. Based on experimenting with threshold value on fingerprints with different types of disease was determined that disease such as Acrodermatitis prefers lower threshold value because of need to detected smaller spots in fingerprint image, where diseases such as Fingertip eczema and Varucca vulgaris had better results with bigger threshold value that eliminated unneeded small spots in fingerprint.

The last part of image preprocessing is **background extraction**. In this process, background is detected and map that contains information of background / fingerprint area is created. This will allows other components to complitly ignore background and give even more precesly results. This step was implemented using *advanced morphological transofrmations, Dilation* and *Erosion*, as well as *Thresholding* and *Gaussian blur filter*.

Figure 7.5: Left - tresholding for Acrodermatitis, right tresholding for Eczema and Verruca Vulgaris.

Figure 7.6: Left - input image, right Background map.

7.2 Block Orientation Field

The orientation field is one of the most commonly extracted features, since it used for many purposes: classification [11], detection of singular points, detection of fingerprint alterations, registration before matching, matching performance improvement and estimating the ridges direction. It describes direction of local ridge structure of fingerprint and provides rich information that is used for classifying the fingerprint image into one of the several fingerprint classes. The result is relatively smooth and continual image of ridges direction estimate.

If we try to compute orientation field map for fingerprint image that is damaged, we can clearly recognize with the naked eye which parts in the image are defected. This map is used to estimate possible damaged area caused by skin diseases. Orientation map was implementated using the gradient-based block orientation field algorithm. It sptes are

as follows:

1. Compute the gradients g_x and g_y for each pixel at (i,j) using gradient operator. In this case a simple Sobel operator was used.
2. Divide the original image into w x w blocks.
3. Compute the estimation o(i,j) of the ridge orientation for every image block centered at (i,j) using next equations:

$$v_x = \sum_{u=i-\frac{w}{2}}^{u=i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{v=j+\frac{w}{2}} 2\partial_x(u,v)\partial_y(u,v)$$

$$v_y = \sum_{u=i-\frac{w}{2}}^{u=i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{v=j+\frac{w}{2}} \partial_x^2(u,v)\partial_y^2(u,v)$$

$$\theta(i,j) = \frac{1}{2}\tan^{-1}\left(\frac{v_y(i,j)}{v_x(i,j)}\right)$$

Figure 7.7: Equations for estimation of the ridge orientation

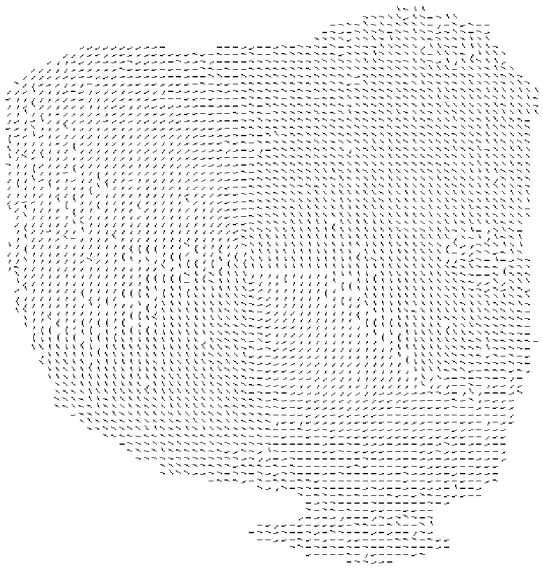

Figure 7.8: Orientation field

The resulting block orientation field is afterwards analyzed for any discontinuities that may occur. Analyzing was done by doing row-wise and column-wise scanning approach that reveals areas of possible damage in fingerprint. For this analyzing was used slighty changed algorithm that is based on Moore neighborhood. Current block at index (i, j) is compared

with his successor and predecessor. In case that the differences between current block and his predecessor and successor blocks were in both case bigger than 45 degrees, then current block will be marked as damaged. Based on experiments, this version of block orientation field algorithm showed better results then standard version and therefore it was used.

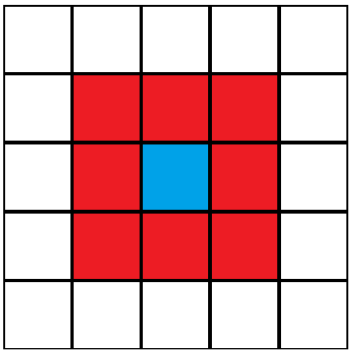

Figure 7.9: Moore neighborhood.

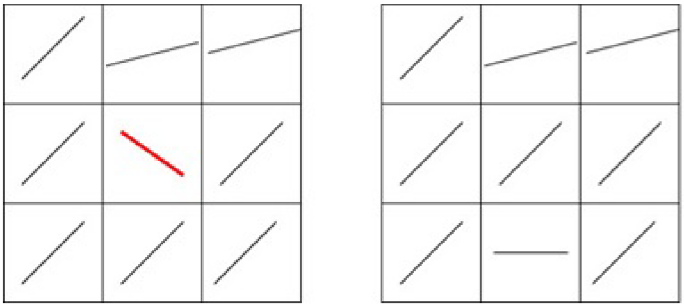

Figure 7.10: Left - block marked as damaged, right - block marked as healthy.

In several other papers that were using orientation field algorithm the size of blocks was usually 16 times 16, but for creating this application blocks of size 8 by 8 were used. The main reason behind using smaller block size is that usually straight white lines that were caused by disease were not detected as damaged areas. Negative side of picking lower block size then usual is that a plenty of small areas, which represent noise in image, are falsely marked as damaged. This problem is solved by setting potentially damaged blocks to marked back as healthy if they don't have at least two damaged blocks in their surrounding. This will allow removing noises that were detected as damaged blocks.

Based on count of potentially damaged block application is able to determinate percent of damage in fingerprint and to conclude if it's able to reconstruct fingerprint.

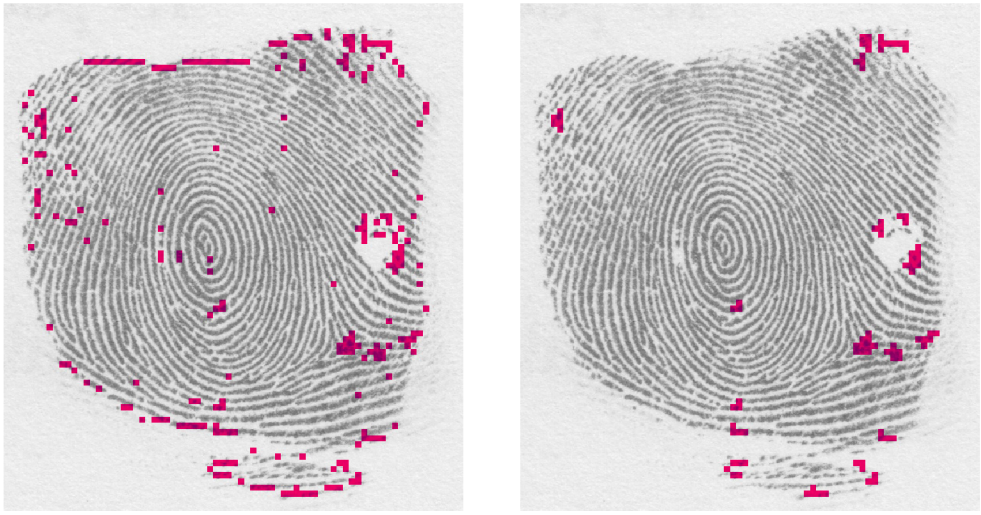

Figure 7.11: Left: damaged blocks before filtering, right: damaged blocks after filgering.

7.3 Damaged Area Extractor - DAE

Skin diseases creates/leaves a trace in fingerprint image that we can simply call damages. These damages are oftly unique and can be easily distinguishable in fingerprint image. The main characteristic of Eczema and Verruca Vulgaris is that they create white damages inside fingerprint. Because Blob detection algorithm is capable only of detecting closed contours, first step in detection these two diseases were extracting damages in fingerprint image. Therefore, **Damaged Area Extractor** (shortly DAE) algorithm was created.
This algorithm has task to extract white areas that are probably damages. That means that, algorithm should extract all white areas that are not „usual“ white spaces between papillary lines.

First step was to compute the median of thickness of papillary lines. This information will help the algorithm to ignore undamaged white areas between papillary lines. In the next step programs goes through the whole image pixel by pixel. Then creates a square with the size of median. Its center is positioned on current pixel. After this part, number of white and black pixels is calculated. If the ratio of white and black pixels is greater then 4:1 then block the will be filled. This method allows detection of all kinds of areas except the normal area between papillary lines. Using the background map, algorithm ignores blocks that are centered in background and that blocks are marked as black(healthy).

Result: Median of distance between papillary lines

```
blockSize = median(papillary lines thickness);
for i = blockSize/2; i < rows; i = i + 1 do
    for j = blockSize/2; i < cols; j = j + 1 do
        create block with center in pixel(i,j);
        compute number of white/black pixels;
        if whitePixels:blackPixels > 4:1 then
            blockColor = white;
        else
            blockColor = black;
        end
    end
end
```

Algorithm 1: DAE algorithm

Result of DAE algorithm is ideal for detection of diseases that can have smaller damages and can be used by blob detector. But in case of Verruca Vulgaris, we don't need to detect thin straight lines, as matter of fact these types of damages should be ignored. The soulution for this kind of problem was to multiply the size of block for Verruca Vulgaris by 2. Bigger block size allows algorithm to ignore minor thin damages and focus on bigger (thicker) damages, and detected damages will have more roundy shape (compared to eczema where damages have more pointy shapes). In pictures were shown difference between DAE algorithm for

Eczema and for Verruca Vulgaris.

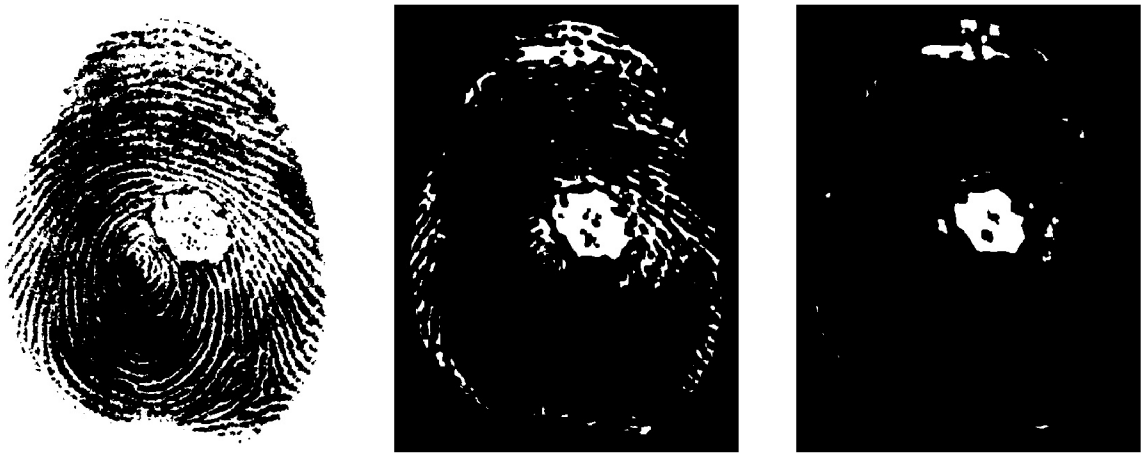

Figure 7.12: 1. Input image after preprocessing. 2. DAE result for Eczema. 3. DAE result for Verruca Vulgaris.

There is one more step that is needed to be done before resulting image could be used by blob detector. Resulting image from DAE for Verruca Vulgaris can have small black spots inside detected damages. This can create problems inside blob detector, which can have false negative result for this disease. Therefore, next process is to make edges of filled areas round and potentially fill the gaps. This is done using functions cv::dilate() and cv::erode(). Effect of dilate operator [123] is to gradually enlarge the boundaries of regions of foreground pixel and effect of erode operator is to gradually shrink the boundaries. After analyzing fingerprint images in the database one more important property is detected. Although wart creates white spots in fingerprint, often these spots are not filled and contain small black spots inside them. Last step is to remove black parts inside filled areas. This is simply done by using function cv:findContours() with important flag RETR_EXTERNAL which allows to detect only contours that have no parents.

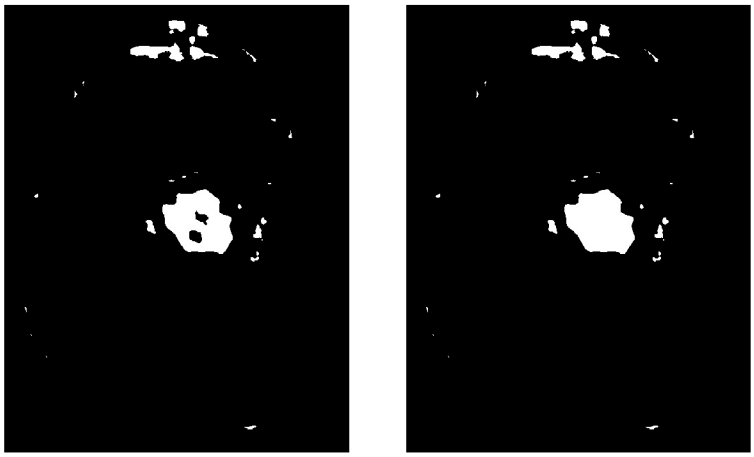

Figure 7.13: Left: input image, right: damage area map.

One of the main unique characteristic of acrodermatitis is that fingerprint have many small so called “cheetah” spots. These spots can be located anywhere on fingerprint, and after image preprocessing these spots are clearly visible and can be detected using blob detection. Therefore there was no need to use DAE algorithm for Acrodermatitis. The important difference between image for Acrodermatitis detection was, that it needed lower threshold value because spots can be very small and using bigger treshold would just merge spots and blob detection would not recognize it.

7.4 Disease Detector

The disease detection is implemented using blob detection algorithm. Library OpenCv provides a convenient way to detect blobs and filter them based on different characteristics.

7.4.1 Blob detection algorithm

A blob is a certain object that represents a certain area of a frame. They are identified because they differ from other pixels in the frame. Blobs can be different things like: hands, faces, balls, etc. In this case blobs will represent damaged areas. The overall goal is to label each pixel within a blob with the same label number. The first stage in achieving this is to iterate through all the pixels, checking the label number of neighbouring pixels as you go. A buffer of equal dimensions as the original image (i.e. one buffer location per pixel) is needed to store the pixel labels. The buffer is initialised to all zeros, which equates to unlabelled. Scanning from top left to bottom right, the labelling kernel is applied per pixel (pixel position X). This is used to check the labels of neighbouring pixels (pixels A, B, C and D). The kernel shape means only neighbours that have already been labelled will be checked [1].

Figure 7.14: Pixel Labelling Process. Source: [1]

7.4.2 Filtering Blobs by Color, Size and Shape

The parameters on SimpleBlobDetector [2] can be set to filter only specific types of blobs.

- By color – This filter allows to set the intensity of blobs that will be detected. Values are in range <0, 255> where 0 represents darker blobs and 255 lighter blobs.
- By area – This filter allows to set minimum and maximum sizes of detected blobs. Measurement unit for this filter is pixel.
- By shape - This filter has 3 different parameters that closely describe shape of detected blobs.

  – Circularity - this parameter simply measures how close shape of blob is to circle. E.g. hexagon has lower circularity then circle, square has lower circularity then hexagon etc. Formula for computing circularity is:

$$\frac{4\pi Area}{(perimeter)^2} \tag{7.1}$$

  Based on this formula circle has circularity 1.00, square 0,785, etc.

– Convexity is defined as the (Area of the Blob / Area of it's convex hull). Now, Convex Hull of a shape is the tightest convex shape that completely encloses the shape.

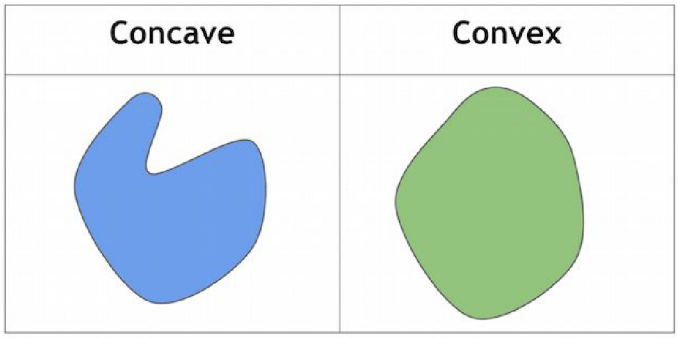

Figure 7.15: Blob convexity. [2]

– This measures how elongated a shape is. For example, circle has value 1, ellipse between 0 and 1 and line has value 0.

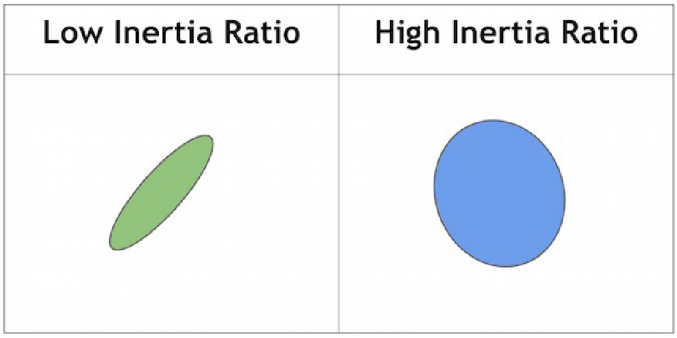

Figure 7.16: Blob intertia ratio. [2]

7.4.3 Sub-detector for Acrodermatitis

Based on fact that main characteristics of acrodermatitis is a large number of small black spots, detector is configured in following way:

Color	Area	Inertia ratio	Circularity	Convexity
black	<30, 300>	<0.55, max>	<0.50, max>	<0.1, max>

Figure 7.17: Blob parameters for detection acrodermatitis

In case that count of detected blobs is bigger than 60, presence of acdrodermatitis is postitive in fingerprint.

7.4.4 Sub-detector for Atopic eczema

For this disease goal is to detect white straight lines.

Color	Area	Inertia ratio	Circularity	Convexity
white	<300, 13000>	<0.10, 0.30>	<0, 0.1>	<0.55, max>

Figure 7.18: Blob parameters for detection atopic eczema

7.4.5 Sub-detector for Wart

For this disaese goal is to big round white areas.

Color	Area	Inertia ratio	Circularity	Convexity
white	<500, 100000>	<0.60, max>	<0.50, max>	<0.6, max>

Figure 7.19: Blob parameters for detection verruca vulgaris

Using the output of *cv::SimpleBlobDetector*, which is vector or *Keypoints*, that contains position and size of detected blobs, we are able to classify contours in image based on detected disease. This allows application to improve visualization and separate damages in fingerprint image.

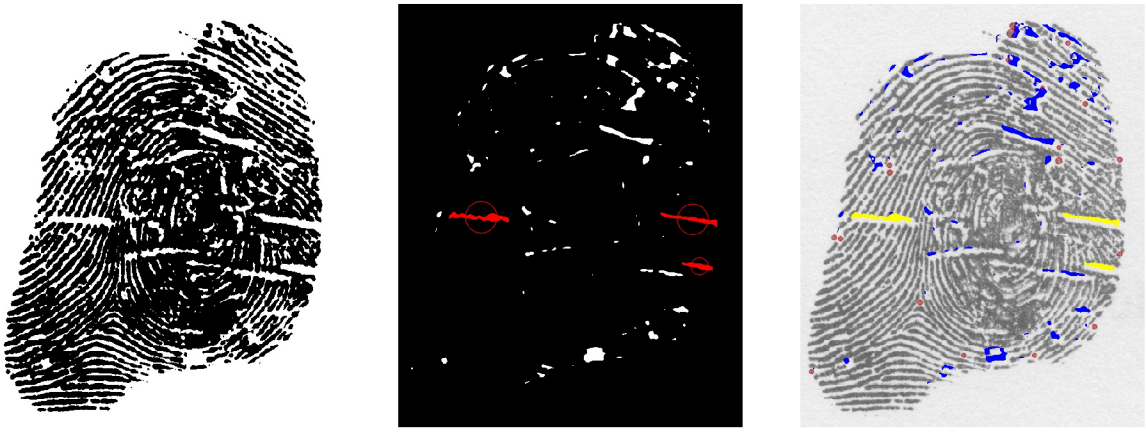

Figure 7.20: Process of visualization

7.5 State map

Area in fingerprint image could be classified into three classes(states): *background, healthy* and *damaged*. Output of 3 above detection algorithms had to be transformed into map with given states. Using *background map* from preprocessing, we are able to mark background areas in each state map. Classification of pixel values in state map:

- 0 < - Pixels with value lower then zero represents background areas
- 0 = - Pixels value equal to zero represents healthy areas of fingerprint
- 0 = - Pixels value bigger then zero represents damaged areas of fingerprint

Positive pixel value represents degree of damage, the bigger value means the bigger damage in fingerprint area.

Process of creatring State map - Each detector creates matrix, where black color represents healthy area and white stands for damaged area. This matrix is used and transformed to State map using next algorithm:

Result: State Map
initialize resolution;
divide image into blocks;
if *block in background* **then**
    blockValue = -1;
else
    blockColor = compute avarage pixel value in block;
end

Algorithm 2: Creating State Map

Using the structure of State Map we are able to compute damaged percentage for earch detector. Earch State Map has it's own weight and its based on percentage of damaged area in fingerprint. By default, weight for earch detector is between 1 and 3. This kind of approach allows detectors with higher percentage of detection to have bigger impact on whole detection process.

7.5.1 Final State Map

After computing State Map for earch Detector, application merges State Maps into one Final State Map. This map represents combination of three detectors: Orientation field, DAE and Blob detection. Final State Map is one of final results and is computed using

next algorithm:

```
Result: Final State Map
weightSum = compute sum of method weights;
for i = 0; i < rows; i = i + 1 do
    for j = 0; i < cols; j = j + 1 do
        damageSum = 0.0;
        for map : stateMaps do
            damageSum = maps.getDamage(i,j) * getWeight(map);
        end
        damageVal = damageSum / weightSum;
        finalMap.setDamage(i, j, damageVal);
    end
end
```

Algorithm 3: Final State Map

Final step is computing damage percentage in Final State Map which is displayed in GUI as resulting damage.

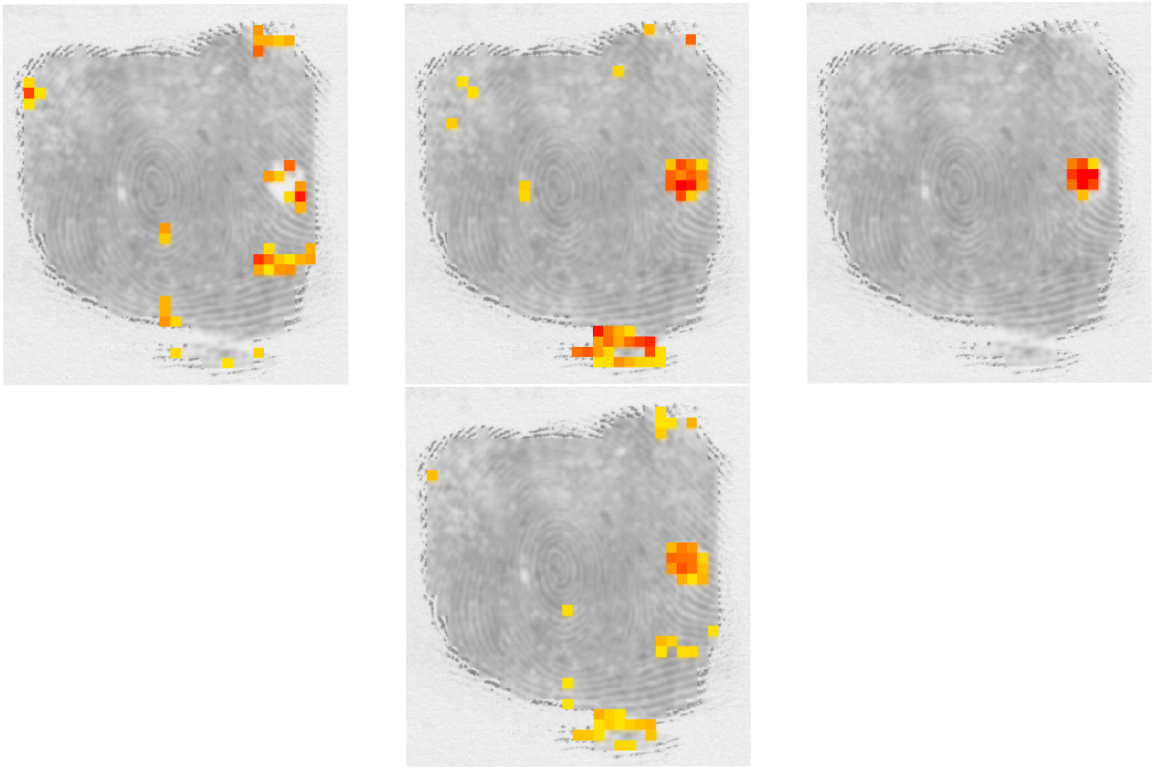

Figure 7.21: State maps - Orientation detector, DAE, Blob detector, Combined

Chapter 8

Experiments and Results

This chapter deals with description experiments resulting application and their results. Application was continuously tested during implementation of individual parts. This testing was very important as it allowed the algorithms to be corrected if it was needed.

8.1 Experimenting

While developing the application, different types of experiments were constantly performed, on all parts of application. The results of experiments are:

- **Image Preprocessing** - This part of application had huge impact of detection process. During experimentation was noticed that using lower treshold value gave better results for Blob detection of Acrodermatitis, and using bigger treshold value improved results of Damaged Area Extractor.
- **Orientation field** - Choosing lower block size then standard allowed algorithm to detect even small defects in fingerprint image. But, this allowed algorithm to detect delta lines or even noise as defects. Solution for this problem was filtering, damaged blocks that don't have atleast 2 damaged neighbors, are considered as wrong detection and their state is set to „healthy".
- **Damaged Area Extractor** - Algorithm showed promissing results, but sometimes background area in fingerprint image was recozgnized as damaged. This was solved using background map, which allowed DAE to ignore background area.
- **Blob Detection - Eczema** - Blob Detector for Eczema is configured to be able to detect straight lines. The problem accures when these lines are connected in fingerprint image, which basicly means that they are not straight lines anymore, therefore Blob detection is negative.
- **Blob Detection - Acrodermatitis** - Application was developed in way to have the biggest possible accuracy. Therefore, parameters for detection of acrodermatitis, are set to detect more roundy black spots in image, which are characteristic for this disease and not so for others. Small spots, that has shapes or rectange, are ignored because they can occur in other types of disease, which would lowered the accuracy of application.

experiment-eczema-3.jpg

Figure 8.1: Example of negative detection because straight lines are connected.

8.2 Testing database

As mention before, the application was tested on database created by Research group STRaDe, Department of Intelligent Systems at Faculty of Information Technology of Brno University of Technology. For developing and testing of application, were selected fingerprint required using dactyloscopic card. This group of fingerprints showed, from given groups, best quiality and at the same time this group was the largest, containing more then 380 fingerprints.

	TP	FN	FP	TN
Acrodermatitis	7	5	13	357
Atopic eczema	89	83	63	147
Verruca vulgaris	7	10	87	288

Figure 8.2: Rejected and accepted samples.

	FAR	FRR	F1	ACC
Acrodermatitis	0.0351	0.4167	0.4376	0.9529
Atopic eczema	0.2739	0.4825	0.5494	0.6129
Verruca vulgaris	0.2320	0.5882	0.7727	0.1262

Figure 8.3: Detector accuracy measures.

8.2.1 Disease Detector Results

Second part of application is detection concrete disease in fingerprint image. Testing was undergone on group of fingerprint images taken from dactyloscopic cards. Total number of test fingerprint images is 382 . Table 8.2 shows the numbers of fingerprints images that were correctly / incorrectly detected. TP (True Positives) represents number of images that were correctly accepted, FN(False Negatives) represents number of images that were incorrectly rejected, FP(False Positive) stands for number of images that we incorrectly accepted and TN(True Negatives) represents number of images that were correctly rejected.

8.2.2 Possible Extensions and Enhancements

The major areas in which the program could be enhanced are:

- Detection

  Concentration of disease in fingerprint can vary in different patient. Based on amount of detected blobs (for Acrodermatitis), size of detected blobs(for Verrica vulgaris), or length can be estimated probability of detected disease. Figure A.5 shows difference high concentrated and less concentrated acrodermatitis in fingerprint.

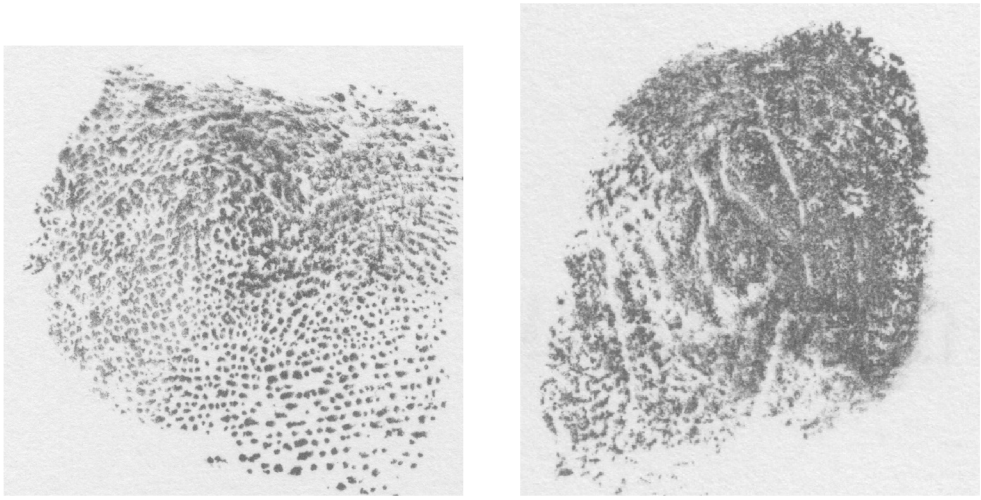

Figure 8.4: Concentration of acrodermatitis in different fingerprints. Source: database

- Speed

  Every sub-detector works with different input image therefore whole detection process could be implemented to work parallel.

- Other diseases

  So far, the application is capable detecting only three diseases: Acrodermatitis, Atopic eczema and Varruca vulgaris. There is still room for implementing detection for other diseases.

Chapter 9

Conclusion

This thesis deals with detection skin diseases in fingerprint images. The goal was to design and develop methods that will extract damaged area in fingerprint image and based on geometry properties and color of these areas to determinate which disease patient probably present in fingerprint image. The goal is met and blob detector for three types of skin diseases was developed: Acrodermatitis, Atopic eczema and Verrica vulgaris.

Based on analyzing provided database of fingerprint images affected by skin diseases following method were implemented: block orientation field, damaged areas finder and disease detector. The best results were achieved by using different properties in the damaged areas finder for each type of skin disease, allowing this method to focus on extracting only particular types of damages that are characteristic for given skin disease.

The disease detector uses Blob algorithm for detection of damaged areas. Using this method, program reached an accuracy of 95.3% for acrodermatitis, 61.3% for atopic eczema and 77.2% for verruca vulgaris.
The resulting program is a GUI application that allows the user to load fingerprint image, view and save the results. It can be used as an analytical tool for future researchers.

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Appendix A

Experimental results

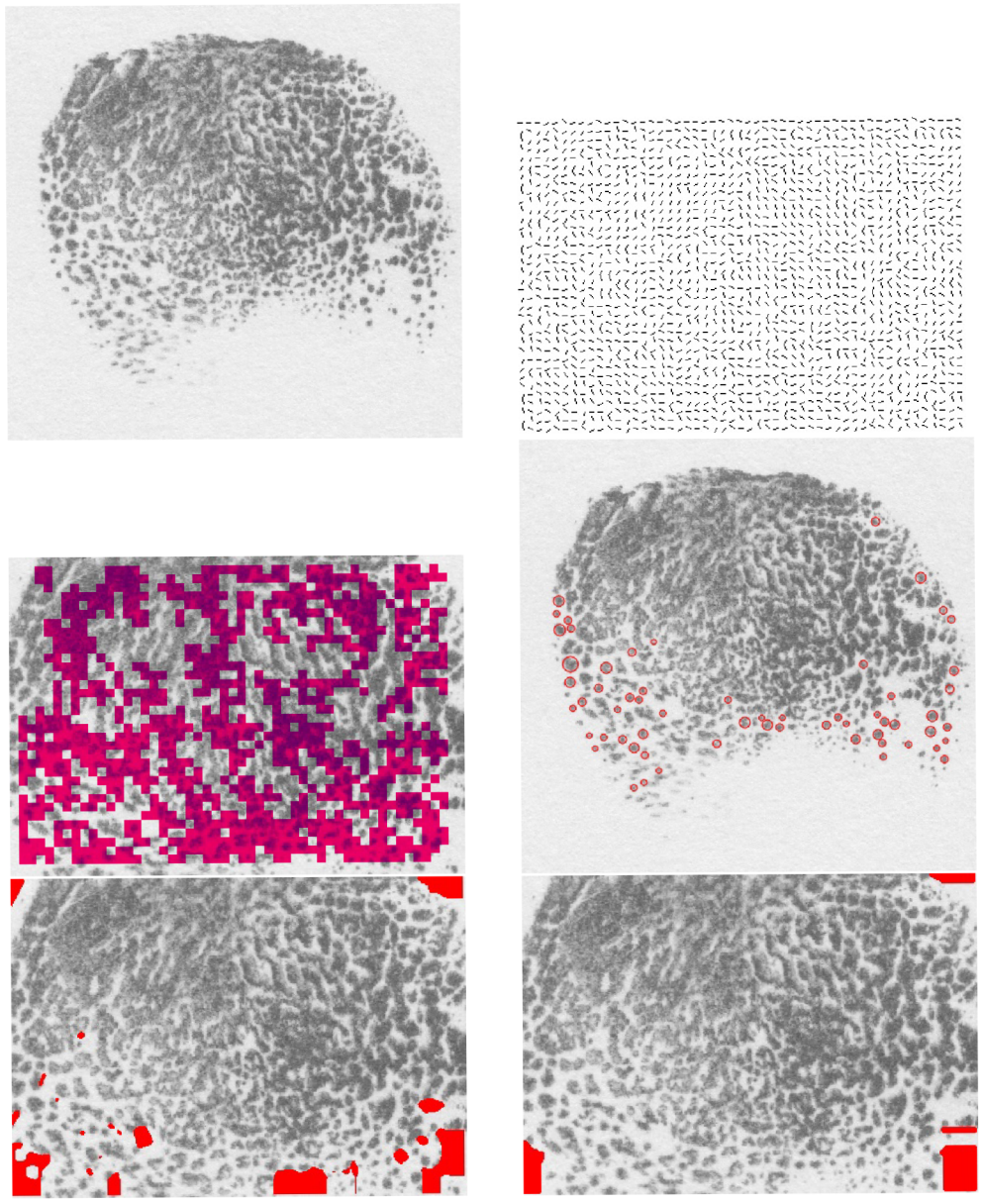

Figure A.1: Results for image affected by acrodermatitits.

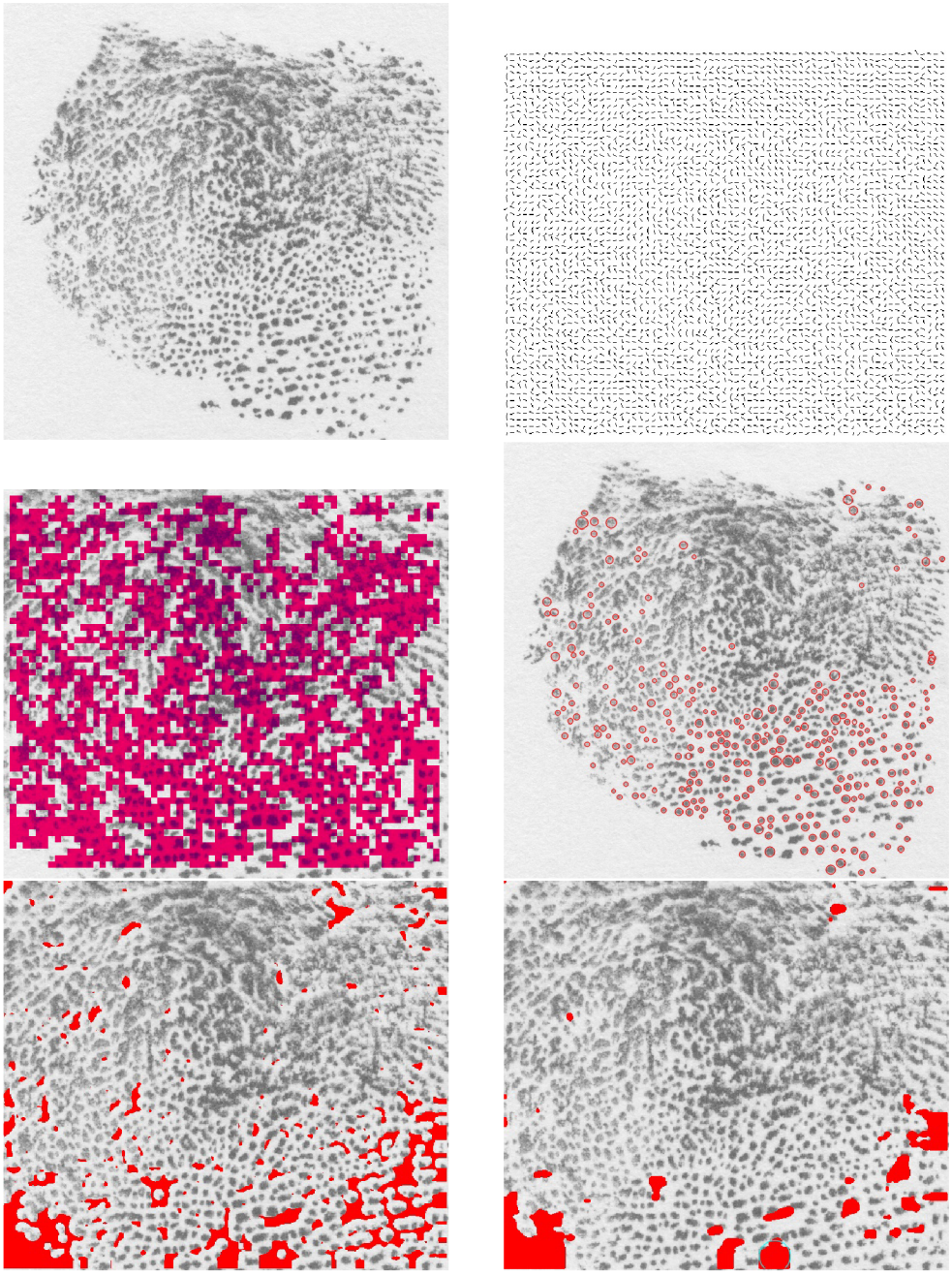

Figure A.2: Results for image affected by acrodermatitits.

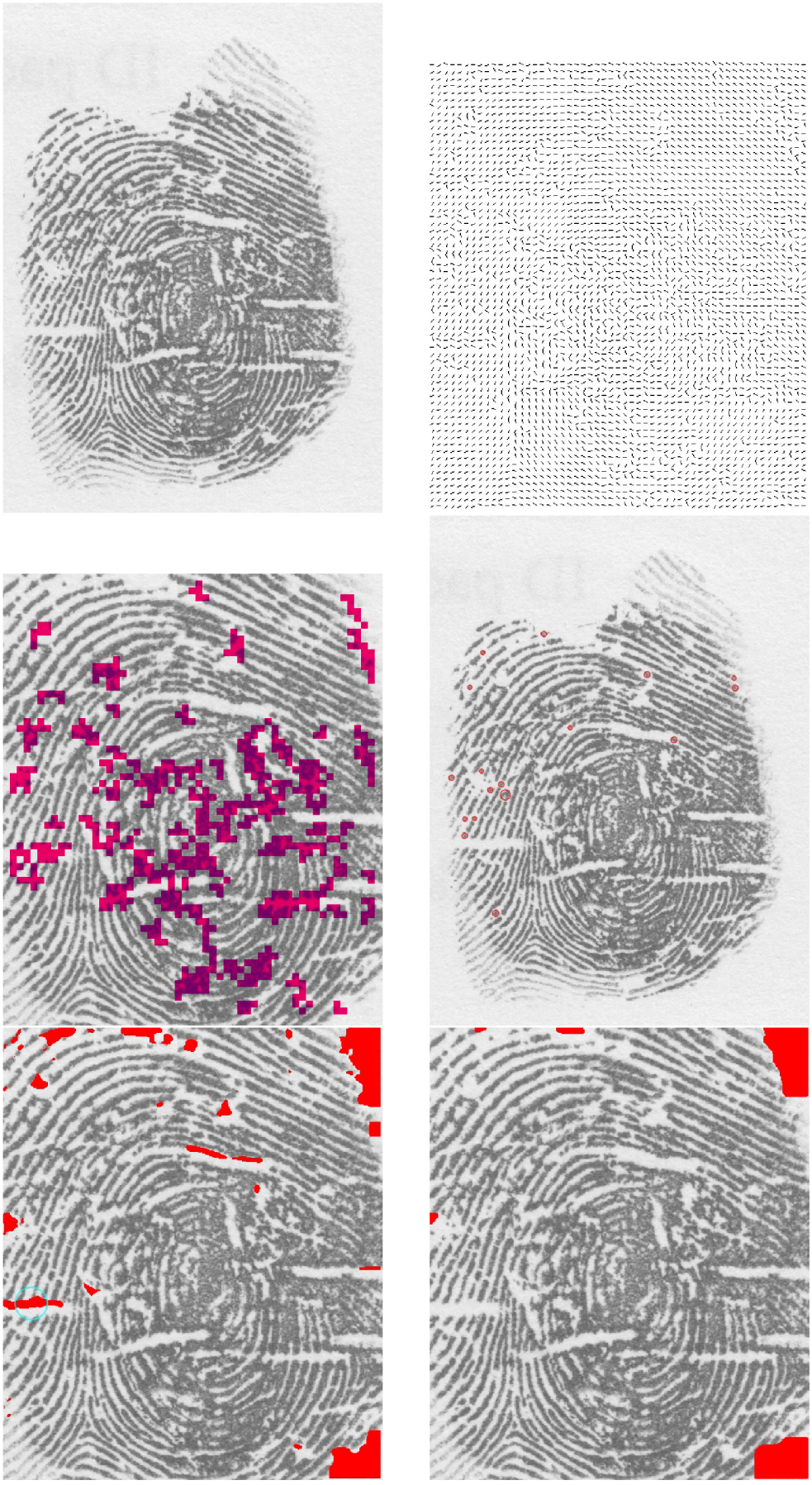

Figure A.3: Results for image affected by atopic eczem.

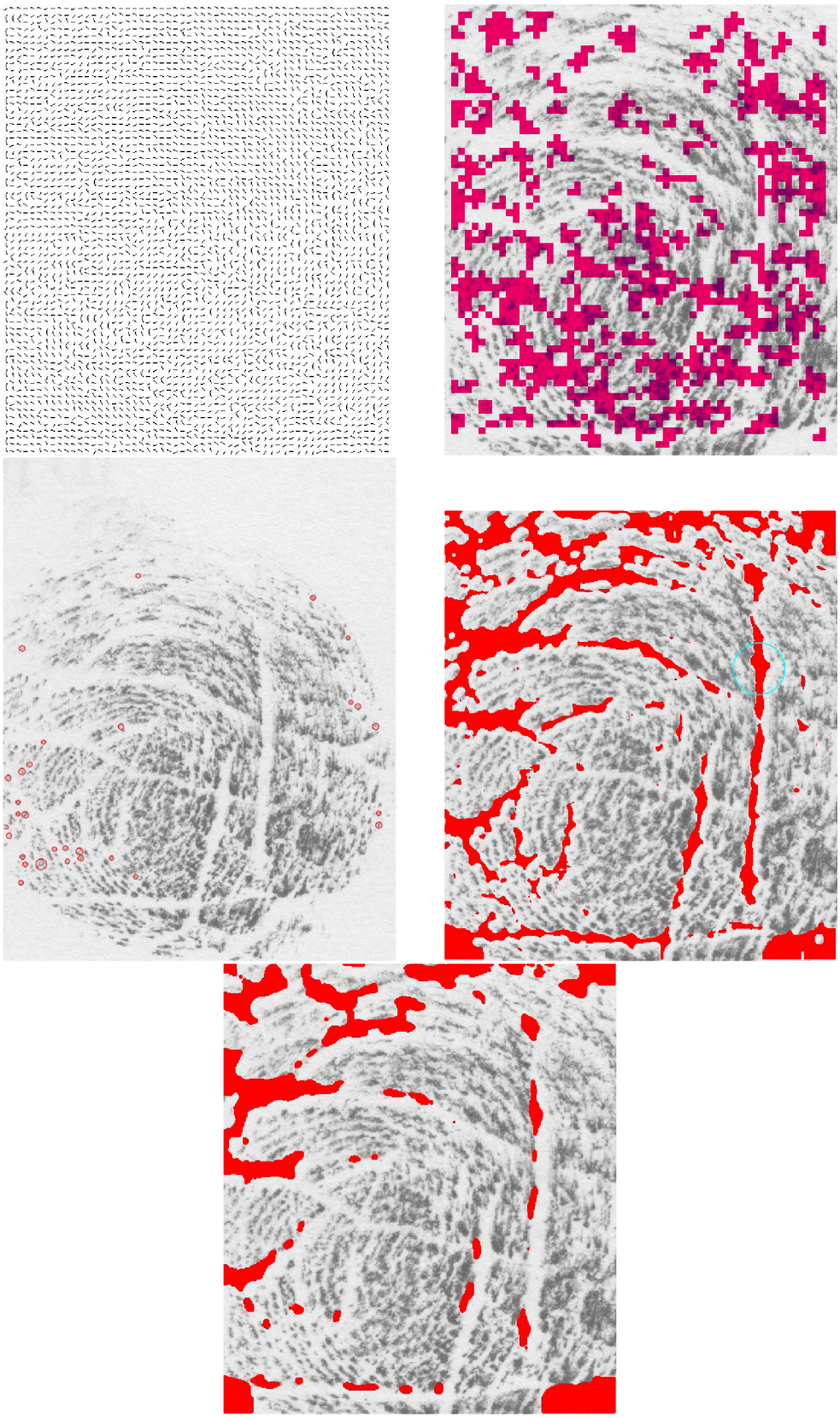

Figure A.4: Results for image affected by atopic eczem.

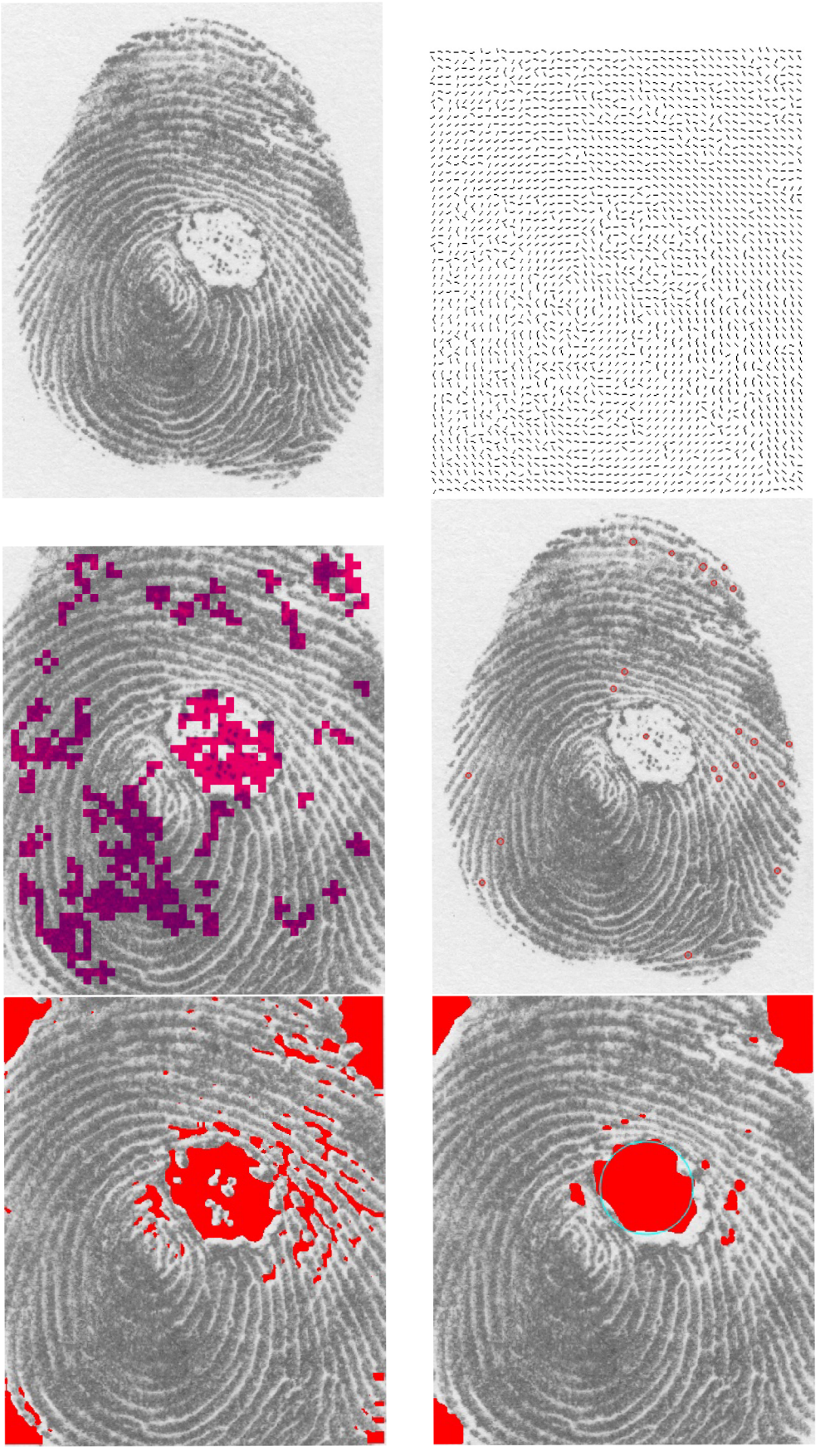

Figure A.5: Results for image affected by atopic eczem.