Chapter 7

Processing of fingerprints influenced by skin diseases

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7.1 Introduction

Human beings have always had a need for a secure world, and with the speed of technology development in the recent past years, this topic is becoming more and more important. Technology affects almost every corner of our lives: work, home, family and leisure. Our society has become more mobile, more electronically connected and less place-dependent. Humans want to have their technological devices, data, bank and other accounts, companies, cars or other possessions secured. However, traditional representations of identity such as passwords or cards no longer offer such security. Passwords are easily breakable and can be forgotten; cards can be stolen or lost. Biometric technologies are based on recognition of biometric traits of individuals, such as face, speech or fingerprint recognition, and they represent the most promising way how to provide security and represent identity in our growing modern world [1].

Fingerprint-based systems are the most widely used biometric technology. Although the individuality of fingerprints was well known already in the ancient times, it was not until 1880 when Henry Faulds published a work that introduced the possibility of using fingerprints for the purpose of human identification [2]. Since that time, fingerprint technology has been evolving and nowadays fingerprint recognition systems have been applied in a variety of areas [1]. They are used not only in forensics for criminalistic purposes but also as an access method to facilities, computers, mobile phones or electronic banking; as a data protection method and for civil identification (passports, driver licenses, national IDs), not to mention applications in government, commercial financial sector, education or health care [1]. This technology has been well accepted by people and we use it on a daily basis. However, there is a significant number of people who cannot use fingerprint systems as easily because their fingertip skin is affected by some kind of skin disease. As these systems count heavily on the structure of an individual's fingertip papillary line pattern that positively determines their identity, people suffering from skin diseases

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might be discriminated against as their papillary patterns may be impaired. It is very likely that fingerprint devices have not been designed to deal with damaged fingerprints, and therefore after scanning the fingerprint, they usually reject it.

In some cases, the condition of an image obtained from the damaged fingerprint is not even good enough for further processing, but in others, the damage is minor and the condition of the fingerprint image should not be an obstacle for papillary lines and minutiae extraction, and further matching. The challenge now is to recognize the presence of skin diseases in fingerprint images, provide sufficient algorithms that will detect them and, if possible, eliminate their influence on the fingerprint recognition process.

7.2 Damaged fingerprints

Undamaged or perfect fingerprint is only a theoretical term. In real life scenario, flawless fingerprint cannot be achieved. The only possible way is to synthetically generate a fingerprint. That is because the original finger is very often somehow damaged, the acquirement method/technology is not perfect, the environmental conditions are not ideal, therefore the resulting fingerprint has some damages. These damages can be basically divided into three groups: *finger and user condition*, *sensor effects* and *influence of the environment*. Information in this subsection is based on [3].

An ideal fingerprint has nicely visible ridges (papillary lines), which are clearly distinguishable from a background—see Figure 7.1 (fingerprint acquired by Sagem MSO300 optical reader). The best choice could be such fingerprint reader technology, which delivers black and white images—e.g., pressure sensitive sensor BLP-100 from the BMF company (seated in Kawasaki, Japan). The majority of sensors delivers fingerprint images in gray-scales, i.e., sometimes it is difficult to distinguish ridges from the background, especially if there are some distortions on finger or coming from the environment (e.g., dirty area of the fingerprint reader). If a histogram of an ideal fingerprint is computed, there should be only two peaks visible—one representing black (ridges) and one representing white (background and valleys). This distribution is not present very often—see Figure 7.2 (left fingerprint acquired by Biolink optical reader, right one by Veridicom capacitive reader).

Figure 7.1 Nearly ideal fingerprint with nicely visible ridges

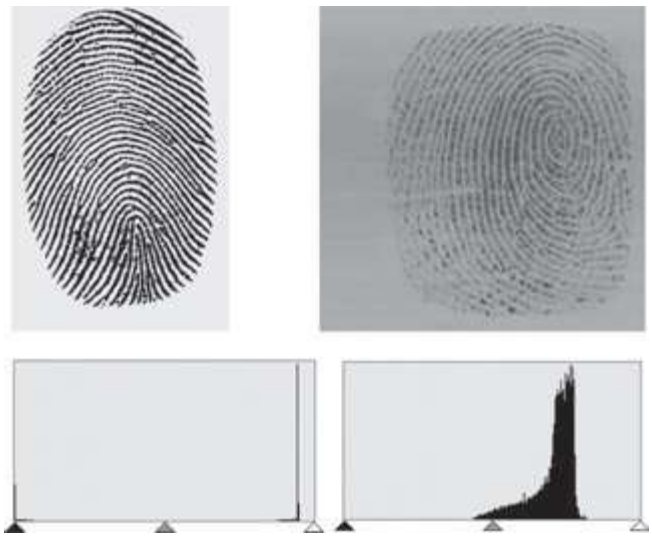

Figure 7.2 Images and histograms of high (left) and low (right) quality fingerprints

All deviations from an ideal fingerprint show low-quality index and the algorithm has to consider whether this fingerprint could be used for further processing or not. This will be described in Section 7.3. Now the focus will be put on description of various distortions, which could be detected in fingerprints and their cause.

7.2.1 Finger and user condition

First phenomena that are connected to the finger itself will be discussed. The **dirt on the finger** can be caused by a few grains of dust, small particle or a greasy finger from some meal. Liquids or generally conductive materials are one of the most problematic types of dirt. For every sensor technology, the most problematic type of dirt is different. These phenomena can be in conjunction with the **dry or moist finger**. Sweaty fingers for example could be assigned to both groups. The effect of moisture or dryness of the finger is very significant. It is also a very frequent way of damaging the fingerprint. Investigated user can be very nervous which leads to sweaty or extremely dry fingers. On the other hand, in the everyday usage, fingers can be moist after using some lotion or they can be simply recently washed. The skin resistance which is important for some sensors can be up to ten times higher or lower than the average value. These two phenomena are discussed more thoroughly in previous part. The **physically damaged finger** is common in some groups of users, namely, among people who are working manually. In their jobs, some abrasions or cuts are inevitable. If it is only a small injury or every day wear damage the papillary lines will regenerate. On the contrary, a deep wound will affect the papillary lines forever. Fingers can be also damaged by **skin diseases**. That will be introduced in Section 7.3.

The second part of this category is phenomena caused by users when acquiring the image. One of them, usually caused by inexperienced users, is small or insufficient **contact region**. That simply means that the finger was presented to the sensor in a way which allows only a partial acquisition of the fingerprint. The small contact region can also be caused by extremely low **pressure**. The other way around, very high pressure can create a black oval instead of the fingerprint image. When the pressure is somewhere between these extremes, it can cause either very thick or very thin papillary lines. It is very sensor dependent what the "right" pressure is. There is an endless number of movements that users can do when showing the **noncooperative behavior**. It can be dynamic or static behavior which is done on purpose, i.e., it is not an accident. The line between an unintentional wrong usage and a noncooperative behavior is very thin. Nevertheless, there are users who resent biometric systems or just try to push to its limits. They can move the finger or change the pressure while the sensor is acquiring image. The other possibility is the static behavior like a rotation of the finger, a small contact region with just a side of the finger, etc.

7.2.1.1 Dirt on fingers

The first category of distortions in fingerprints is caused by dirt on fingers. This could be caused by miscellaneous materials, e.g., oil or fat, detergents or soaps, crumbs, glue and hair. For the acquirement, it is not so important whether the finger was made dirty before touching the scanner surface or whether the finger was made dirty because of touching the scanner surface, which was dirty from the previous user. Important is that the finger surface is dirty during the scanning process.

We acquired a small database (approx. 200 images) with fingerprints, which are influenced by some dirt. The analysis of this database has shown that there are the following groups of changes in acquired fingerprints:

- *Thicker ridges*—if the user has normal skin conditions, i.e., not too dry and not too wet skin, and the pressure to the sensor is average, it is possible to acquire very nice fingerprint images. However, if any of these conditions is not fulfilled then the quality of acquired fingerprint is getting lower. Thicker ridges could be caused, e.g., by increased pressure to the sensor surface [see Figure 7.3(a)—fingerprint acquired by Bergdata thermal reader]. Other cause for thicker ridges is very often wet and oily (sweat coming out from sweat glands is spreading over the ridges) finger surface [see Figure 7.3(b)—fingerprint acquired by SecuGen optical reader]. Nevertheless, other materials in our environment can cause thicker ridges as well—for example, hand cream Nivea [see Figure 7.3(c)—fingerprint acquired by SecuGen reader], detergent Cif for cleaning surfaces in kitchen [see Figure 7.3(d)—fingerprint acquired by SecuGen reader], liquid industrial soap [see Figure 7.4(a)—fingerprint acquired by Sagem MSO300 optical reader], cleaning paste for very dirty hands Solvina [see Figure 7.4(b)—fingerprint acquired by Sagem MSO300 optical reader], shower gel and shampoo Umbro [see Figure 7.4(c)—fingerprint acquired by UPEK EikonTouch 300 capacitive reader] and dish washing detergent Lena [see Figure 7.4(d)—fingerprint acquired by UPEK EikonTouch 300 capacitive reader].

Figure 7.3 Fingerprints with thicker ridges caused by (from left to right) (a) increased pressure to the sensor surface, (b) wet finger surface, (c) hand cream Nivea and (d) detergent Cif for cleaning surfaces in kitchen

Figure 7.4 Fingerprints with thicker ridges caused by (from left to right) (a) liquid industrial soap, (b) cleaning paste for very dirty hands Solvina, (c) shower gel and shampoo Umbro and (d) dish washing detergent Lena

- *Broken ridges*—one part, discussed by previous thicker ridges could be continued here—if the finger is very dry, many technologies have troubles to acquire such ridges, especially capacitive and optical technologies (see Figure 7.5(a) fingerprint acquired by Biolink optical reader and Figure 7.5(b) by Veridicom capacitive reader). Very dry fingers could cause troubles for criminal praxis as well, because the latent fingerprint traces left on the crime scene have really low quality. However, there could be other influences which have an impact to the low quality of broken ridges, for example, cleaning paste for very dirty hands Solvina (see Figure 7.5(c)—fingerprint acquired by Sagem MSO300 optical reader; compare this image with Figure 7.4(b)), earth dust (see Figure 7.5(d)—fingerprint acquired by Veridicom capacitive reader), fine sand (see Figure 7.6(a)—fingerprint acquired by Veridicom capacitive reader), metallic dust (see Figure 7.6(b)—fingerprint acquired by Veridicom capacitive reader) or generally any kind of dust or crumbs.

(a) (b) (c) (d)

Figure 7.5 Fingerprints with broken ridges caused by (from left to right) (a) and (b) very dry finger skin, (c) cleaning paste for very dirty hands Solvina and (d) earth dust

(a) (b)

Figure 7.6 Fingerprints with broken ridges caused by: (a) fine sand and (b) metallic dust

- *Additional false minutiae points*—this is a very special case, but not so rare. In this case, the thickness of the dirt has to be approximately same as the ridge. This dirtiness could be hair, fiber or any similar thin and long object. If this object is crossing ridges in these crossings, there could be falsely detected minutiae points, especially false multiple bifurcations (see Figure 7.7—left fingerprint acquired by TBS touchless reader and the right fingerprint by e-field reader). Very small dust pieces or crumbs can connect ridges and on that place there could be detected bifurcation as well. Optical technology is a little bit untypical for thin and long objects on the finger or scanner surface because these objects can have dark or bright color; therefore, they will represent two different minutiae points—dark objects will represent false additional bifurcations (or multiple bifurcations) and bright objects will represent false line endings. Other bigger objects are very often detected as "something wrong" in the image and this area is denoted by low confidence, i.e., these areas are not used for minutiae detection any more. However, smaller objects are taken as ridges and therefore the algorithms for quality estimation do not detect them.

Figure 7.7 Fingerprints with additional minutiae points caused by fiber (left) or hair (right)

One very special case which does not belong to any of the previous categories is the use of medicaments. One very famous example is the use of capecitabine (cancer treatment medicament), which is called chemotherapy-induced acral erythema. This is not the only case—application of acids or alkalis or other corrosive liquids, or use of abrasive materials can destroy the skin structure and therefore ridges can fully or partially disappear.

7.2.2 Sensor effect

Phenomena connected to the sensor are dangerous because they influence all users using the device. In the registration phase, a common error among all users can be made, which is a potential security hazard. In the verification phase, this new common error can make the verification or the identification of the user harder.

The first phenomenon is the **dirt on the surface** of the sensor. While the dirt on the finger is associated with grease or small dust, the surface of the sensor can be polluted much more. There can be grease from several fingers, it can be wooden, metallic or earth dust or fine sand because the sensor is used in a factory or outside. When the amount of dirt is higher, the sensor cannot even recognize that there is a finger on its sensing area. When the dirt on the surface comes from the papillary lines, it is called the **latent fingerprint**. This is fingerprint residues from previous users and not only that it can create fake papillary lines for the current user but sometimes it can be reactivated creating a great security hazard. There is also a possibility of the **physical damage** of the sensor. Whether it is intentional or caused by accident, the sensor can be damaged, but usually not destroyed. The resulting damage is different for every sensor technology. For example, when using the optical technology, the usual damage is a visible crack on the protective glass. The **sensor technology** itself has a large impact on how the fingerprint will look like. For example, some technologies like the ultrasonic one can get the image from a deeper level of skin and the resulting image is then without shallow scars. Some technologies get ridges as a white color, some get ridges as a black color and some technologies get colorized image (basically photo) of the fingerprint.

7.2.3 Influence of the environment

The last group has an influence usually both sensor and user/finger.

The **vibration** can create a blurred image or damage the device internally. It is common in mobile devices when they are used in the means of transport or similar situations. The **temperature** usually influences the fingerprint indirectly by high moisture of the finger or on the other hand, extreme dryness of the finger when it is very cold. But the temperature can also have an impact on the sensor technology. There are technologies that are more sensitive to the surrounding temperature than others. The **surrounding light** is another sensor technology specific phenomenon. It influences only sensors which have a light sensing unit, i.e., the optical or electro-optical technology. A problematic situation occurs when the sensor is large and the finger is small. The uncovered edges of the sensor create the fingerprint image from the surrounding light and not from the finger itself. That can lead to different results when using the sensor in different light conditions. The **electromagnetic radiation** is the last phenomena. In some cases, it can influence the device as a whole. It can even change the information that is transported from one part of the biometric system to the other. This can then in more sensitive sensor technologies lead to a blurred image.

7.2.4 Examples of damaged fingerprints

Figure 7.8 shows a fingerprint image damaged by various factors. We can see wrinkles in the middle of the fingerprint, not ideal contact region (image is not centered) caused by the user, latent fingerprint (right and up side) and the dark parts in the corners are caused by the surrounding light.

Figure 7.8 Fingerprint damaged by various factors

Figure 7.9 Fingerprint damaged by a detergent

Figure 7.10 Fingerprint with physical damage

Fingerprint in Figure 7.9 is damaged by shower gel which was used before the fingerprint acquirement. Various sensor technologies also create completely different images in comparison with Figure 7.8.

In Figure 7.10, another sensing technology can be seen. On the left bottom part of the image, a small crack in the protective glass of sensor can be seen. In the middle of the fingerprint, there is a long scar. That means sensor and finger are physically damaged in this image.

7.3 Diseased fingers

Skin diseases represent a very important, but often neglected factor of fingerprint recognition. It is not possible to say in general how many people suffer from skin diseases, because there are so many various types of skin diseases [4,5]. The situation after the successful recovery of a potential user from such skin diseases is, however, very important for the possible further use of fingerprint recognition devices. If the disease has attacked and destroyed the structure of ridges in the epidermis and the underlying dermis (the so-called dermoepidermal

junction—the connection of the top two layers of the skin), the ridges will not grow in the same form as before (if at all) and therefore this user could be restricted in his future life by being excluded from the use of fingerprint recognition systems, though his fingers no longer have any symptoms of the skin disease. It is almost impossible to get to a fingerprint database with skin diseased users and with information about their disease. Creation of this type of database is even harder because of the cooperation of technicians with medical doctors and patients. On the other hand, there is not a reasonable way of testing how recognition algorithms can cope with skin diseases [8].

Skin is constantly being regenerated. A keratinocyte ("skin cell") starts its life at the lower layer of the epidermis (the basal layer), which is nourished by blood vessels and is supplied with nerve endings from dermis. The cell migrates upward from the basal layer to the stratum corneum (the outermost skin layer). During 4 weeks, the cell undergoes a series of changes, gradually flattening out and moving toward the surface. Then it dies and is shed. This physiological process can be negatively affected in many diseases of the skin. The epidermis is not supplied with blood vessels, but has nerve endings. The shape of the dermoepidermal junction basically forms the structure of ridges [8].

In most cases of dermatological disorders, we find a lot of changes in the ultrastructure of the skin, including the epidermis and dermis. There is often inflammation (inflammatory cells), atrophy or hypertrophy, fibrotisation and many other changes visible under the microscope. These differences result in changes of color (optical characteristics), changes of dermal vessels and capillaries (blood perfusion) and changes of elasticity and thickness of the skin (optical characteristics after pressure change) [8].

The first group represents diseases causing **histopathological changes of the epidermis and dermis**—these diseases usually cause problems for all kinds of fingerprint scanners, because they can influence either the color or the internal structure of the skin. The most common representatives of this group are [4,5]: hand and fingertip eczema, dyshidrosis, tinea, pyoderma, pitted keratolysis, pyogenic granuloma, systemic sclerosis or Raynaud's phenomenon [8].

The second group represents diseases causing **skin discoloration**—these diseases may cause problems for optical fingerprint sensors and also for sensors which use a fingerprint antispoof detection check based on the color or spectral analysis of the human skin. Typical representatives are [4,5]: macular drug eruptions and rashes in infectious diseases (hand, foot and mouth disease, scarlet fever, secondary syphilis, Kawasaki's disease), pitted keratolysis, Raynaud's phenomenon, xanthomas, carotenosis or hereditary hemorrhagic teleangiectasia [8].

The third group represents diseases causing **histopathological changes at the junction of the epidermis and dermis**—these diseases could cause structure changes underneath the skin at the junction between dermis and epidermis—i.e., in the area from which ultrasonic fingerprint scanners acquire fingerprint pattern images. Typical representatives are [4,5]: hand eczema, verruca vulgaris (warts), psoriasis or epidermolysis bullosa [8].

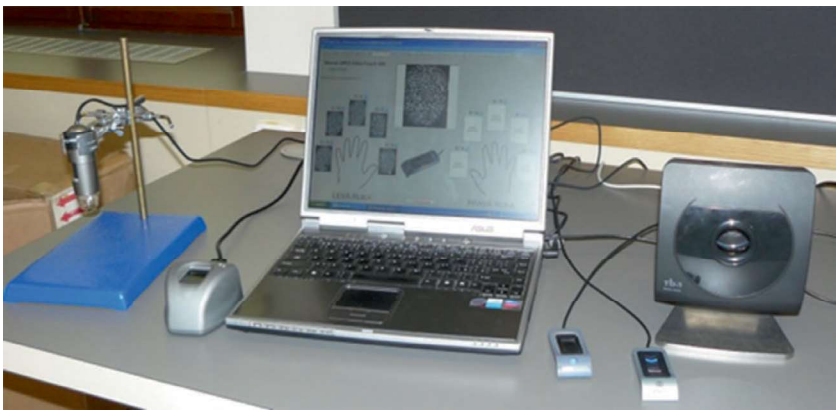

Figure 7.11 Workplace for acquirement of diseased fingerprints

As has been shown before, working with fingerprints that come from users with skin diseases can be very difficult. Our database with diseased fingerprints were created in cooperation with the University Hospital Olomouc (Czech Republic), using the supportive consultations from the St. Anne's University Hospital in Brno (Czech Republic) and the private dermatologic clinic in Darmstadt (Germany)—see the next section. In Figure 7.11, the workspace which was sent to the dermatologists to acquire fingerprints can be seen. It contains a 3D touchless and touch optical sensor, a sweep and touch capacitive sensor and a digital microscope. Some institutions also acquired fingerprints using a dactyloscopic card. Each image in the database has anonymized information about the patient, severity and type of disease. There are thousands of fingerprints in the database. The size of the database and the described unique information about them is the reason why the database is one of the few, if not the only one in the world. Therefore, it is perfect for studying what damage each disease does. In Figures 7.12–7.15, the results of disease-affected fingerprint data collection are shown. The name of the disease and description are given in each figure heading. The codename of applied capturing principle is stated under each subfigure. We use the following codenames: CRD (dactyloscopic card), MSO (Sagem MSO 300), E500 (UPEK Eikon Touch 500), EII (UPEK Eikon II), TBS (TBS 3D Enroll 2011), DIN (Dinolite) [6–8].

7.4 Description of the unique database with diseased fingerprints

The acquired database contains over 2,000 fingerprint images from patients suffering from various kinds of skin diseases. In total, 12 particular skin diseases were obtained [9–11]. The database was thoroughly analyzed in order to find any common features in the damage caused by the diseases. Features that were found

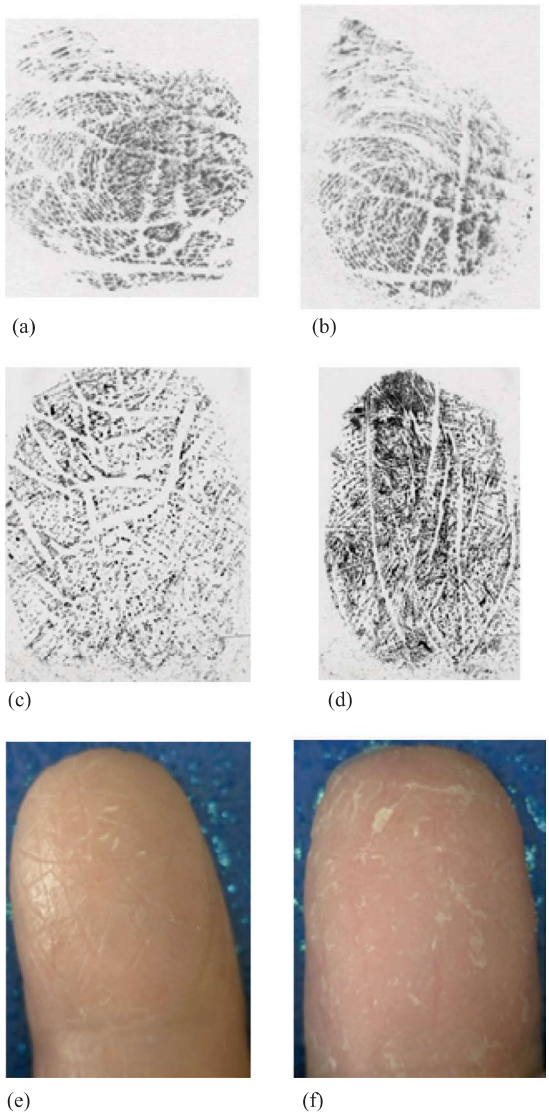

Figure 7.12 Fingertip eczema—a severe form: (a and b) CRD, (c and d) MSO and (e and f) DIN

were classified into five categories that are later used for the disease detection itself [11].

In this section, database analysis is given, as well as characteristics of each skin disease from the database and characteristics of the specific influence they have on the resulting fingerprint images.

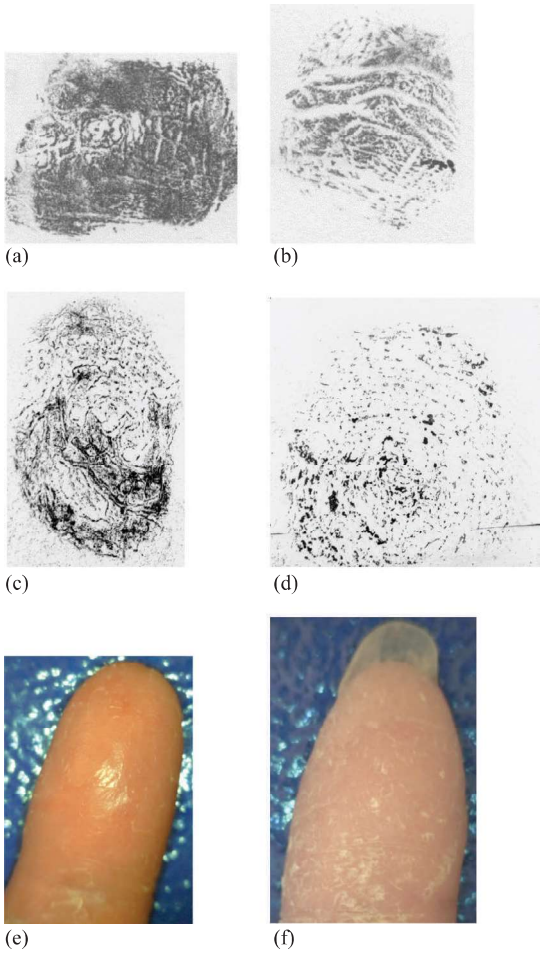

Figure 7.13 Psoriasis—a full seizure: (a and b) CRD, (c and d) MSO and (e and f) DIN

7.4.1 Database analysis

The raw diseased fingerprint database was first analyzed in order to provide a solid foundation for future research. For every particular disease, common signs among all fingerprint images affected by this disease were found and a general description of each disease and its influences was defined. Based on these descriptions and sets of common signs and their frequencies, the diseased fingerprint images were classified into five categories. These categories are later used in the actual detection of the damaged areas in a fingerprint image and they help to divide the large detection task into smaller bearable parts [11].

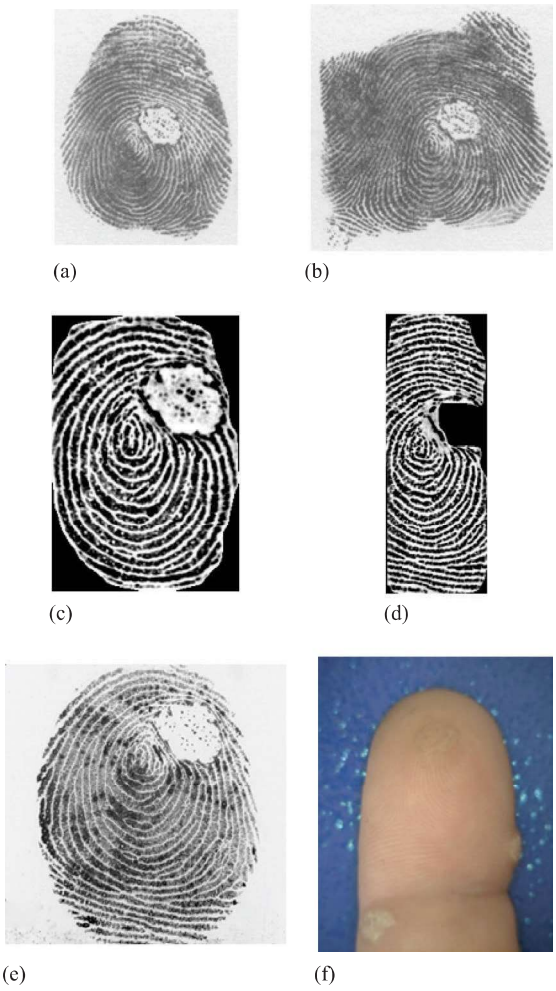

Figure 7.14 Verruca vulgaris (wart): (a and b) CRD, (c) E500, (d) EII, (e) MSO and (f) DIN

Most of the fingerprint images come from a dactyloscopic card. The number of fingerprints of each disease is displayed in Table 7.1 [12].

By observing and comparing the fingerprint images, 12 common features were defined, seven of them are local features [12]:

- straight lines (SL),
- a grid (G),
- small papillary lines disruptions (PLD),
- small "cheetah" spots (CS),
- larger round/oblong spots (ROS),
- large irregular spots (IS) and
- dark places (DP),

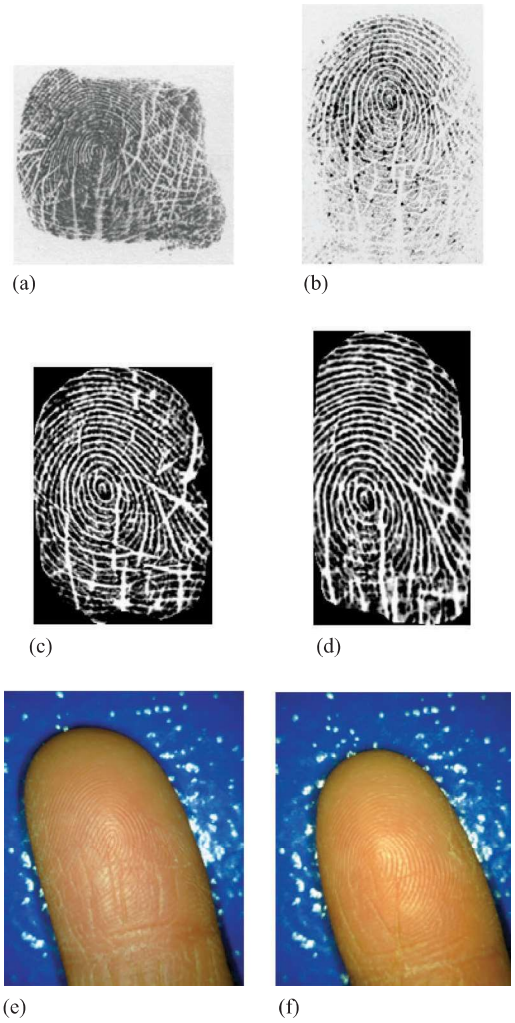

Figure 7.15 Colagenosis: (a) CRD, (b) MSO, (c) E500, (d) EII and (e and f) DIN

the other five were global image patterns [12]:

- blurriness of (parts of) the image (B),
- a significantly high contrast of the image (HC),
- the entire fingerprint area affected (EA),
- total deformation of the fingerprint image (TD) and
- a significantly high quality and healthy fingerprint (HQ).

For every disease, its image features were counted (see Tables 7.2 and 7.3). Fingerprint images obtained from optical scanners were excluded as their character is significantly dissimilar to the others. The actual number of images taken into account is stated in the column "sum."

Table 7.1 Database content [12]

Disease	No. of fingerprints in the DB	Percentages	No. of patients
Fingertip eczema	1,107	51.132	17
Psoriasis vulgaris	326	15.058	9
Dyshidrotic eczema	247	11.409	4
Hyperkeratotic eczema	118	5.450	2
Verruca vulgaris	96	4.434	4
Scleroderma	50	2.310	1
Acrodermatitis continua	40	1.848	1
Colagenosis	36	1.663	1
Raynaud's phenomenon	9	0.416	1
Effusion of fingers	35	1.617	1
Cut wound	18	0.831	2
"Unknown" disease	83	3.834	1
Total	**2,165**		**44**

Table 7.2 Local features of damaged fingerprint images

Disease	Percentages of particular features							Sum
	SL	G	PLD	CS	ROS	IS	DP	
Fingertip eczema	72.03	24.65	15.91	12.24	32.34	16.61	15.73	572
Psoriasis vulgaris	40.37	6.42	2.75	12.84	48.17	32.57	62.84	218
Dyshidrotic eczema	63.11	7.38	14.75	18.03	78.69	29.51	32.79	122
Hyperkeratotic eczema	3.92	0	66.67	15.69	74.51	3.92	5.88	51
Verruca vulgaris	3.17	0	14.29	12.70	74.60	0	25.40	63
Scleroderma	0	0	0	0	0	0	30.43	23
Acrodermatitis continua	14.29	0	0	85.71	60	14.29	65.71	35
Colagenosis	100	78.13	0	0	15.63	0	25	32
Raynaud's phenomenon	0	0	100	0	0	0	0	8
Effusion of fingers	10	0	73.33	43.33	63.33	6.67	13.33	30
Cut wound	93.75	0	0	0	18.75	0	12.50	16
"Unknown" disease	100	86.67	0	0	76.67	30	73.33	30

7.4.2 Characteristics of present diseases

This section gives an overview of all the diseases present in the database, their characteristics and description of their influence on resulting fingerprint images [11,12]. For detailed description of skin diseases mentioned in this section, please refer to [4,5,13]. This section deals with the detection of four of them: *atopic eczema*, *acrodermatitis*, *psoriasis vulgaris* and *verruca vulgaris*.

7.4.3 Fingertip eczema

Fingertip eczema is a very dry, inflammatory, noninfectious disease which occurs on the palmar surface or the fingertips. The skin becomes cracked and scaly, and

Table 7.3 Global features of damaged fingerprint images

Disease	Percentages of particular features					Sum
	B	HC	EA	TD	HQ	
Fingertip eczema	18.01	21.50	40.38	36.36	29.02	572
Psoriasis vulgaris	34.86	27.06	61.93	58.72	18.35	218
Dyshidrotic eczema	30.33	30.33	31.97	29.51	9.84	122
Hyperkeratotic eczema	31.37	29.41	9.80	0	37.25	51
Verruca vulgaris	19.05	80.95	7.94	7.94	76.19	63
Scleroderma	0	0	0	0	100	23
Acrodermatitis continua	48.57	25.71	100	100	0	35
Colagenosis	9.38	40.63	0	0	25	32
Raynaud's phenomenon	0	0	0	0	100	8
Effusion of fingers	23.33	16.67	40	16.67	3.33	30
Cut wound	37.50	68.75	0	0	50	16
"Unknown" disease	30	20	90	83.33	0	30

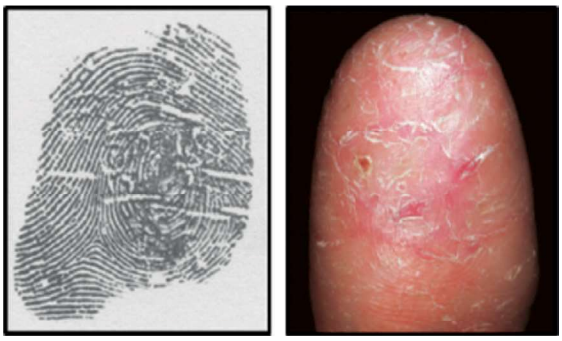

Figure 7.16 Fingertip eczema. Source: Database and [12]

usually starts peeling off which results in exposition of red and tender skin surfaces [4,5,13] (Figure 7.16).

As the number of fingerprints with fingertip eczema in the database is large, a wide range of typical features was observed. There are two groups of these fingerprints: (i) less and (ii) more severely damaged. In the first group of fingerprints, occurrence of thin lines of different directions was typical. These lines often connect or cross each other. In some cases, small round white spots were present, and in others, occasional dark areas make the papillary lines partially unreadable. However, overall, papillary lines of fingerprints of the first group are generally very well readable and it is possible to remove the influence of the disease from the fingerprint.

In the second group, the damage is more severe. Fingerprints are usually almost completely damaged, SL cover the entire fingerprint area and create grids by crossing each other. The background is darker and large IS can be seen. As the papillary lines cannot be seen at all, this type of damage is by no means recoverable.

7.4.4 Psoriasis vulgaris

Psoriasis is a common, chronic and inflammatory disease of the skin which is often indistinguishable from a serious form of hand eczema. It is characterized by dry and scaling plaques covered with dry scales that peel in layers [4,13].

The vast majority of fingerprints affected by psoriasis are completely damaged. Papillary lines are mostly unreadable. The most frequent feature is a large irregular dark spot bounded by a white border. Apart from this feature, the presence of larger dark areas or thick lines is also common, as well as ROS (Figure 7.17).

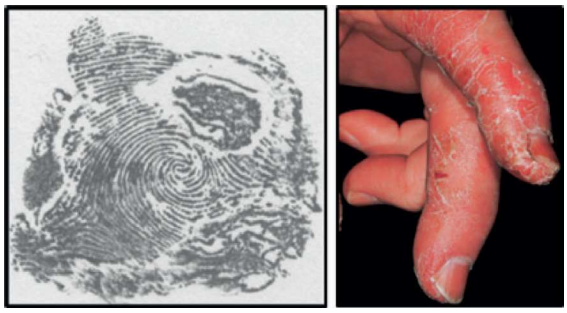

Figure 7.17 Psoriasis vulgaris. Source: Database and [4]

7.4.5 Dyshidrotic eczema

Also known as pompholyx, this disease is a variant of hand and foot dermatitis that makes skin extremely dry. Its typical features are itching vesicles and scales located on the palms and sides of fingers [4] (Figure 7.18).

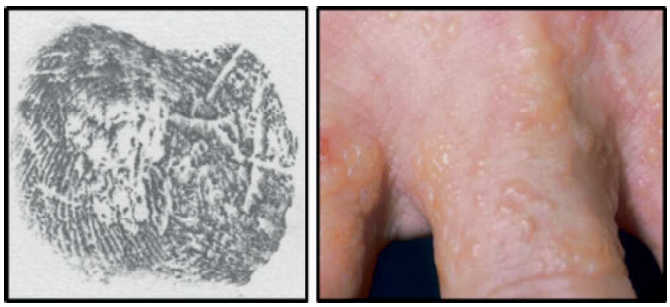

Figure 7.18 Dyshidrotic eczema. Source: Database and [5]

Fingerprint images damaged by dyshidrotic eczema are generally covered with irregular blurred shapes with no specific form. Another typical feature is a thick line. These fingerprints were divided into two groups, according to how severe the damage is. In the first group of less severely affected fingerprints, the entire area of a fingerprint is often covered, but papillary lines remain visible. Papillary lines are

usually disrupted at multiple places and irregular blurred white spots may appear. Fingerprints in the second group are seriously damaged and cannot be repaired. The image area is typically covered by thicker lines in combination with large blurred white spots. Papillary lines are not sufficiently visible.

7.4.6 Hyperkeratotic eczema

A chronic form of hand eczema characterized by the occurrence of orange and brown scales with cracks between them [4,13]. Only one-third to one-half of the fingerprint area is usually affected. Sometimes, only the papillary lines are multiply disrupted. In other cases however, papillary lines are distorted and their direction is difficult to determine. Small-to-medium round spots are likely to be present (Figure 7.19).

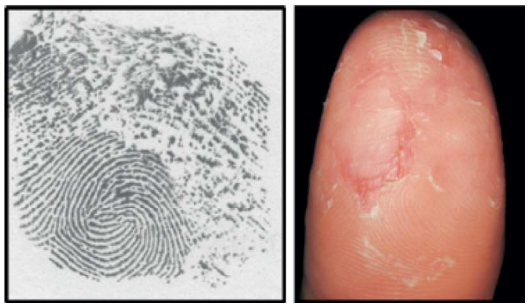

Figure 7.19 Hyperkeratotic eczema. Source: Database and [4]

7.4.7 Verruca vulgaris (warts)

This is a very common skin disease, characterized by the presence of stiff elevated bumps on the skin surface. They grow in size which is in average about 5 mm but can reach up to more than 1 cm. On their surface, tiny black dots may appear [12,13]. The influence of this disease on the fingerprint images is minor and easily removable. Typically, 1–4 round white spots occur, sometimes with black dots in their center (Figure 7.20).

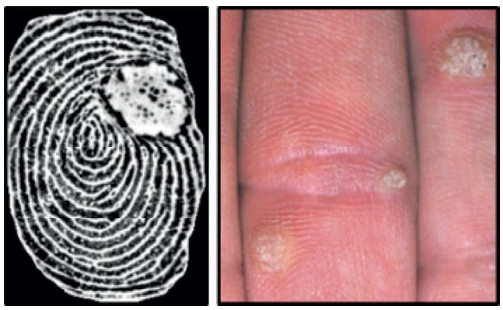

Figure 7.20 Verruca vulgaris. Source: Database and [4]

7.4.8 Systemic scleroderma

Scleroderma is characterized by the appearance of hard, smooth and ivory-colored areas. In the early stage, affected areas are red and swollen; later, they become completely immobile and lose their natural peaked contour [4,13]. The fingerprints in the database did not show any signs of damage. It can be therefore concluded that the number of acquired fingerprints was not sufficient to describe the disease's influence on fingerprint images (Figure 7.21).

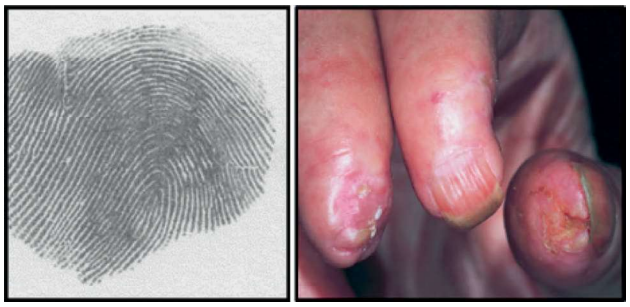

Figure 7.21 Systemic scleroderma. Source: Database and [4]

7.4.9 Acrodermatitis continua

Also known as acrodermatitis continua of Hallopeau or dermatitis repens, this disease is a chronic inflammatory disease of the hands and feet, and one of the less frequent types of psoriasis vulgaris. The outbreak of the disease is accompanied by asymmetric formation of pustules of the fingertips and continues with eruption of fresh pustules with hyperkeratosis and crusting. As the disease progresses, nails can even float away [13].

Fingerprint images are typical for the occurrence of small round spots that look like a cheetah skin and cover usually the whole fingerprint area. Larger oblong or round spots occur as well and SL or cracks are also not uncommon. Papillary lines cannot be recognized at all, and the original structure of the fingerprint is completely covered. Larger dark areas are often present and the spots can be blurred together. Almost in all cases, the fingerprint image is completely damaged and cannot be repaired (Figure 7.22).

7.4.10 Colagenosis

Colagenosis is a connective tissue and inflammatory autoimmune disease. The only typical feature of fingerprints with this disease is thin lines crossing each other. Under these lines, papillary lines are well visible (Figure 7.23).

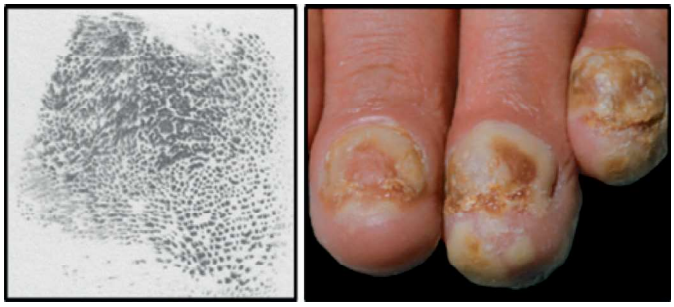

Figure 7.22 Acrodermatitis continua. Source: Database and [5]

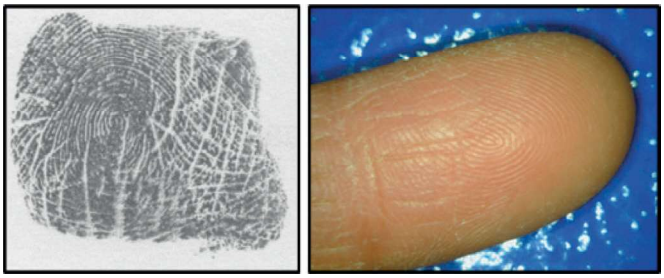

Figure 7.23 Colagenosis. Source: Database

7.4.11 Raynaud's phenomenon

It is a vascular skin disease that often accompanies an associated disease (most often scleroderma). The fingers have sequential discolorations: they first become pale and cold, then white, blue and finally red. This is caused by constrictions of the small arteries and arterioles in fingers [4,13]. As Raynaud's phenomenon causes discoloration only fingerprints in the database are always healthy and undamaged. Disease can be seen in Figure 7.24, left image shows papillary lines on sensor, middle image shows white fingers and right image shows blue color at the end of the fingers.

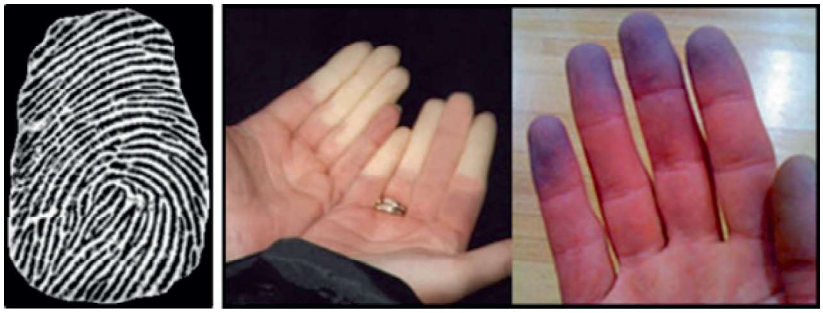

Figure 7.24 Raynaud's phenomenon. Source: Database and [14]

7.4.12 Effusion of fingers

Although being stated as a disease in the database, effusion of fingers is only a syndrome which manifests itself by a strong swelling. It is one of the symptoms of systemic scleroderma, for instance. Papillary lines are typically disrupted in many places, and small to medium spots are present. In general, papillary lines are clearly visible. Sometimes, however, white spots make them unreadable (Figure 7.25(a)).

(a) (b) (c)

Figure 7.25 (a) Effusion of fingers, (b) cut wound and (c) "unknown" disease. Source: Database

7.4.13 Cut wounds

A cut wound typically causes either a SL in a fingerprint image or a more blurred white area. The damage is minor and should not be difficult to remove (Figure 7.25(b)).

7.4.14 "Unknown" disease

Fingerprints of this unnamed disease are totally covered with lines of different thickness and length and are therefore unreadable. They are very much alike those with fingertip eczema (Figure 7.25(c)).

7.4.15 Classification of damaged fingerprint images

Based on the analysis of the database, the diseased fingerprint images were classified into five basic feature classes. Such classification is supposed to help access each type of damage individually and facilitate the detection process. For each disease detector, a different combination of features to detect is chosen, which helps differentiating between signs of particular diseases and correctly determining the type of disease present in the fingerprint image.

7.4.15.1 Straight lines and grids

Under these circumstances, representatives are: fingerprint eczema, cut wound, colagenosis, dyshidrotic eczema, "unknown" disease (Figure 7.26).

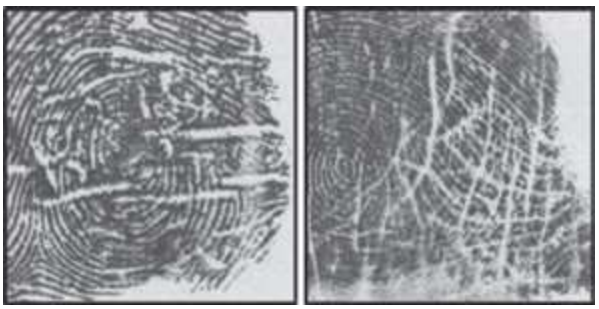

Figure 7.26 Example of fingerprint images with straight lines or grids. Source: Database

(a) (b)

Figure 7.27 Examples of (a) papillary lines disruptions and (b) "cheetah" spots. Source: Database

7.4.15.2 Small papillary lines disruptions

In this case, papillary lines are disrupted at multiple places but no significant damage is present. Representatives are: dyshidrotic eczema, hyperkeratotic eczema, effusion of fingers and fingertip eczema (Figure 7.27(a)).

7.4.15.3 Small "cheetah" spots

The only representative of this group is acrodermatitis (Figure 7.27(b)).

7.4.15.4 Round/oblong spots

Although ROS occur in most diseases, typical representatives with a significant amount of them are verruca vulgaris, effusion of fingers and psoriasis (Figure 7.28).

7.4.15.5 Large irregular spots

Psoriasis and severe form of fingertip eczema often cause extreme damage to the fingerprint and one of their features are also large spots of irregular shapes (Figure 7.29).

Figure 7.28 Example of fingerprint images with white spots. Source: Database

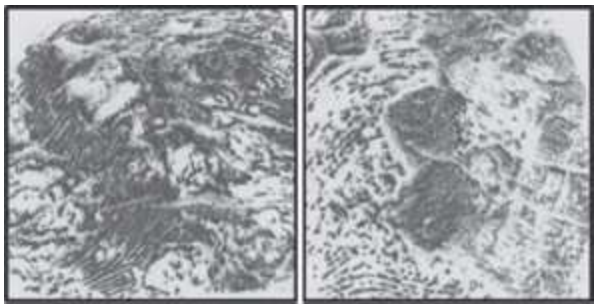

Figure 7.29 Example of fingerprint images with irregular spots. Source: Database

Also, diseases were classified into three categories according to the seriousness of the damage.

1. Minor damage: verruca vulgaris, Raynaud's phenomenon, cut wound, scleroderma.
2. Medium damage: mild form of fingertip eczema, mild form of dyshidrotic eczema, hyperkeratotic eczema, effusion of fingers, colagenosis.
3. Major damage (unrecoverable): acrodermatitis, severe form of fingertip eczema, severe form of dyshidrotic eczema, psoriasis, "unknown" disease.

7.5 Algorithms for dealing with damaged fingerprints

In this section, the specific algorithms used in the disease detector along with their advantages and shortcomings will be discussed, as well as the core methods essential for the program's functionality and data structures used to store and keep important data throughout the process.

7.5.1 Detector

There are three major algorithms that are used for the detection part: *Block orientation field*, *histogram analysis* and *flood fill*. Their combination provides valuable information about the fingerprint quality and character of the possible disease.

The detector uses a few special data structures. The first of them is cv::Mat, a data type implemented in OpenCV used for storing images [10], in other words a matrix of numerical values. The program makes use of this data type not only for keeping the processed images themselves, but also for storing the intermediate steps and StatusMaps. A StatusMap is a data structure that is used for the visualization of the extent of damage in the fingerprint. It consists of an $n \times m$ matrix (cv::Mat), where n is the number of columns and m is the number of rows. Both n and m are always smaller than the width and height of the input image so that the visualization can capture the global extent of damage in $w \times w$ subfields of the image. The values of this matrix are between -1 and 1. Negative values stand for background, 0 stands for a healthy area and positive values imply a damaged area, with 1 being the most damaged.

$$x = \begin{cases} (-1;0) & \text{background} \\ 0 & \text{healthy area} \\ (0;1) & \text{damaged} \end{cases} \tag{7.1}$$

Another essential data structure is the feature. It is used to store the signs of diseases extracted from the image and consists of a feature type, location of the first pixel, size and the exact pixels belonging to that particular area. It is used both for storing the detection results and visualizing them.

7.5.2 Block orientation field

The computation of block orientation field is commonly used in the fingerprint recognition process for the purposes of estimating the ridges direction and classifying the fingerprint image into one of the several fingerprint classes [1,13]. Because a typical fingerprint pattern consists of alternating dark and white lines, this information can be easily processed by a gradient operator that estimates the image gradient for each pixel. This low-level information is gathered and averaged for each $w \times w$ block in the image [12]. The transformation can result in a relatively smooth and continual image of the ridges direction estimates—for a healthy fingerprint of course—see Figure 7.30 on the left.

If we try to compute the block orientation field for a damaged or a partially damaged fingerprint however, we can easily recognize with the naked eye which areas contain possible damage, because the orientation field in these areas will be discontinuous, as displayed in Figure 7.30 on the right. Exceptions to this are the peripheral areas and deltas and cores.

These discontinuities can be detected by scanning the field for differences in direction angles. In the program's pipeline, a gradient-based method of block orientation field computation is used [12,15,16].

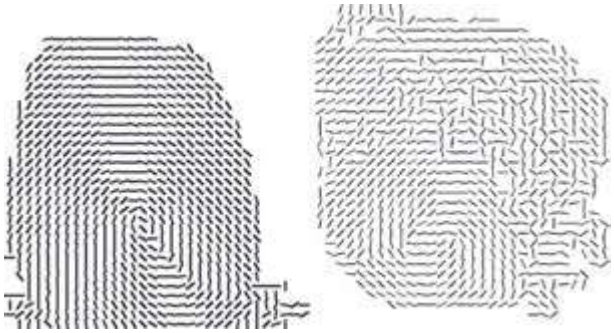

Figure 7.30 Examples of block orientation images (left: healthy fingerprint, right: fingerprint affected by a skin disease)

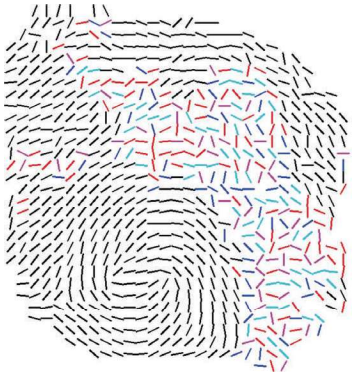

Figure 7.31 Damaged area detected using the orientation field

The resulting block orientation field is afterwards analyzed for any discontinuities that may occur. The analysis is done using a row-wise and column-wise scanning approach that reveals areas of possible damage in the fingerprint. Sometimes, the method detects single discontinuities that may be erroneous, and on the other hand, under different circumstances, one unmarked block may appear in the midst of discontinuous blocks. In order to make the algorithm as accurate as possible, although mistakes never disappear completely, these cases are taken into account. The algorithm handles them by copying the properties of their neighboring blocks (marking the single ones either as alright or as a discontinuity, depending on the neighborhood). Example detection is shown in Figure 7.31.

The advantage of this method is that it is already a part of the standard fingerprint recognition pipeline, so the algorithm can be easily implemented into existing methods. Also, it provides a fairly accurate estimate of the fingerprint damage in the sample. However, it is not always able to detect local damages, such as spots or lines. For this reason, we use the flood fill algorithm. Before that one is

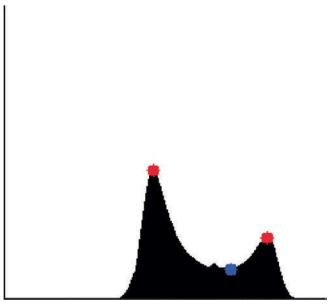

Figure 7.32 A nearly ideal bimodal histogram

explained, however, let's take a look at how analyzing histograms from image subfields can be used to obtain useful information about damage.

7.5.3 Histogram analysis

This method is based on the presumption that a fingerprint image with a high quality consists of equally distributed ridges and valleys. If we assume that ridges are roughly the same dark color while valleys are light-colored, a histogram computed from each subfield of the fingerprint's area should ideally consist of two peaks of approximately the same height and one valley between them. The transition between the peaks and the valley should be smooth, as displayed in Figure 7.32, and the peaks' height difference vary slightly according to the width of ridges in the image. This shape is called bimodal.

On the other hand, the intensity distribution in a fingerprint image part that belongs to a damaged area is not always as equal as in the quality one. Thus, if a histogram is computed for this subfield, it is very likely that it will not have the ideal bimodal appearance as described above. Experiments showed that the majority of damaged areas break the rules of the bimodal histogram. The lower the quality, the less the histogram resembles the ideal one. A nonbimodal histogram always implies a damaged or low-quality area.

At the same time, however, there is a certain percentage of damaged areas whose histograms still fall into the valid category. A damaged subfield therefore does not necessarily imply a nonbimodal histogram. This is due to the fact that a histogram is a measure for the distribution of intensities only and it does not take into account the pattern or neighborhoods of pixels. Figure 7.33 shows examples of invalid histograms.

Figure 7.34 shows an example output of this method, along with the particular histograms that were being analyzed. Red background implies an invalid histogram, green means valid and blue stands for background.

Since the histogram analysis method is an experimental one, its results are not always accurate. The major drawback of this method is its inability to cope with low-quality, especially dark, images. By implementing appropriate preprocessing steps, the method's performance and accuracy can be improved.

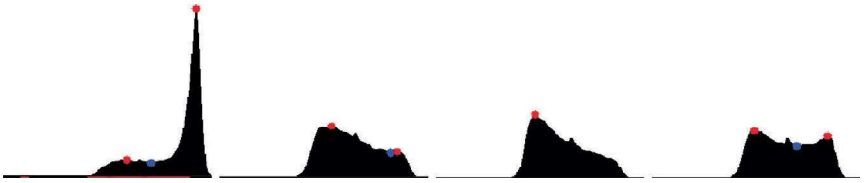

Figure 7.33 Examples of invalid histograms

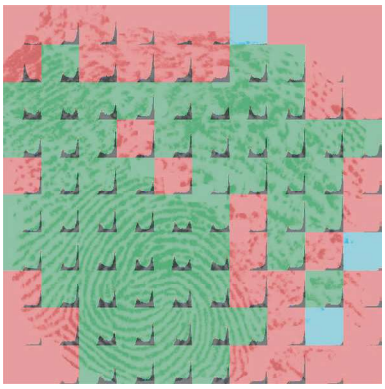

Figure 7.34 Histogram analysis result with particular histograms

Although the method can never find all damaged areas, histogram analysis is able to detect many areas the block orientation field method might have omitted. The sets of damaged areas detected from these two methods are never identical; therefore, the histogram analysis method is extremely valuable for the final determination of healthy areas.

7.5.4 Flood fill

Flood fill is a very well-known algorithm used for graphical purposes [17] and is especially handy for detecting and filling connected single-colored areas of an image. This characteristic was used in the application in order to find local features of damaged fingerprints, such as SL or spots.

For the detection of such features, the Hough transform [18] was initially used, but it was later rejected for its inaccuracy. Flood fill turned out to be far more exact and appropriate. The flood fill algorithm has three parameters: a target color, a replacement color and a start pixel. It is based on examining the color of all pixels in the 4- or 8-neighborhood of the start pixel and changing the color of those pixels that have the target color to the replacement color. Using either recursion or stack/queue, the colored pixels become the next start pixels and the process is repeated. In the end, the entire single-colored area is filled.

In our case, for better memory management, the scanline flood fill algorithm [17] is used. This one is extended by a stack and differs from its basic version by a

Figure 7.35 Extraction of straight white lines

reduced space and time complexity, which is achieved by filling whole lines instead of single pixels. Also, it is able to retrieve all points belonging to the area and store them later in the Feature class. When flood fill is used for a fingerprint image, the sample first needs to be preprocessed in order to obtain a black and white image that can be used as an input for the algorithm. The preprocessing steps are tricky because they heavily depend on the image quality, as well as the type of sensor used for the acquisition. In this implementation, all algorithms are tailored for our internal fingerprint database, in particular, for the fingerprints from dactyloscopic cards.

The preprocessing steps consist of contrast and brightness adjustment, a series of dilations, erosions, closing and opening operators, combined with fingerprint area detection according to [19], Gaussian blur and thresholding (Figure 7.35).

There are four types of features the flood fill algorithm is programed to detect: large white spots, thick white lines, small CS and PLD (for explanation of the groups).

Apart from the algorithm, the flood fill class also enables us to set parameters that closely specify how big the filled areas should be and what shape they should have. The shape's determination is based on the ratio between the longer and the shorter side of the area's bounding rectangle: if it is below 1.8, it is considered round, and if it is over 2.3, it is considered oblong. Others are not taken into account. Thanks to the parameters, it is possible to tailor the results for different detectors.

7.5.5 Methods merging using a status map

All three of the above-described methods detect a different kind of damage in the image and only flood fill provides logically structured results that can be used in classification.

However, connecting the three methods together results in a surprisingly accurate description of the extent of damage in an entire area of a fingerprint

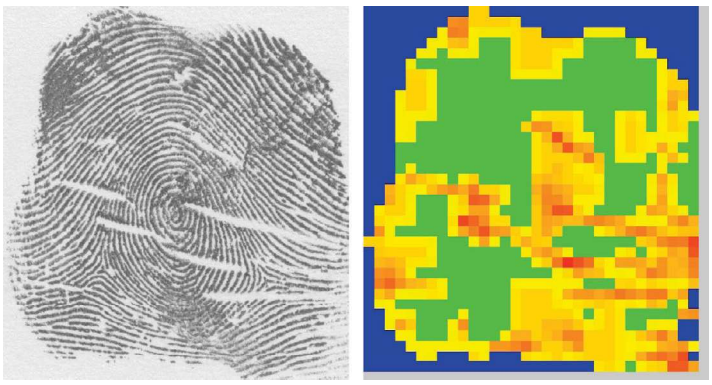

Figure 7.36 Example of a final StatusMap

image. At the end of each detection process, every image pixel is assigned a value between −1 and 1. Negative values stand for background, 0 means a healthy area and positive values indicate damage. The higher the value, the more damaged the area to which the pixel belongs, as explained in the previous parts.

The challenge was to connect these three output matrices together into a so-called StatusMap which would give a good overview of the damage state every $w \times w$ block of pixels.

For the purpose of a correct merge, all methods' output pixel values were limited to nonnegative.

The information about background is stored separately using BackgroundExtractor. This extraction method marks pixels −1 (background) or 1 (fingerprint area) and produces a fourth matrix of pixel values. The resulting StatusMap gives a very good overview of the damage. The right side image of Figure 7.36 is the StatusMap. The blue surroundings is background, green parts show healthy area and everything else shows damaged area (on yellow to red scale − red color is the most damage area).

7.5.6 *Classifier*

The classifier decides based on features extracted by the flood fill algorithm and classifies the fingerprint image, according to the features' numbers, sizes and shapes into one of these six categories: acrodermatitis, atopic eczema, psoriasis, verruca vulgaris, unknown disease or healthy.

In order to determine the decision rules, a script that counted the numbers and types of detected features from the whole database for each disease was implemented. Medians and standard deviations of these numerical values were used to support the Classifier's decision—see Table 7.4.

Given the normal probability distribution, it is supposed that the majority of values are going to be one standard deviation away from median. Then, a significant amount of values will lay two standard deviations away from median and almost no values will be farther. These characteristics are used in order to compute an estimated likelihood that a certain set of features belong to a particular disease.

Table 7.4 Statistics of features extracted from each disease

	Acrodermatitis		Atopic eczema		Psoriasis		Verruca vulgaris	
	Med.	**Std. dev.**	**Med.**	**Std. dev.**	**Med.**	**Std. dev.**	**Med.**	**Std. dev.**
White sp.	5	3.97	5	4.31	8	5.35	1	3.02
Lines	2	1.84	3	3.06	4	2.65	1	1.63
Cheetah sp.	47	42.70	29	17.50	21	19.61	18	10.90
Disruptions	7	8.37	17	19.80	8	9.22	15	39.76

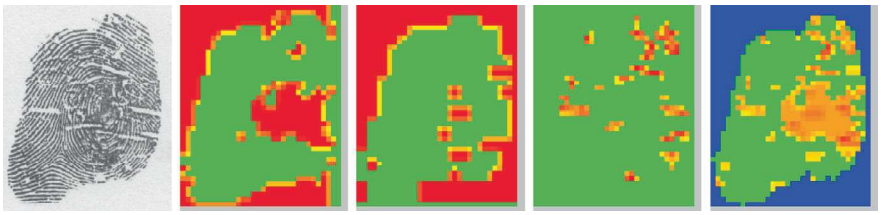

Figure 7.37 Example of the pipeline of StatusMaps and the final distribution of damage in the image (atopic eczema). Green color marks the healthy areas, blue color highlights the background and for the damaged areas, a scale from yellow to red is used. Yellow stands for minor damage, whereas red implies extremely damaged places

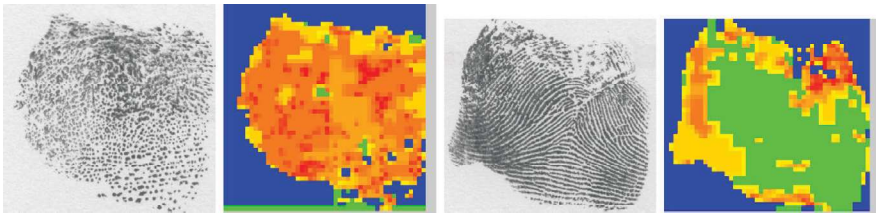

Figure 7.38 Damage detection results. Green color marks the healthy areas, blue color highlights the background and for the damaged areas, a scale from yellow to red is used. Yellow stands for minor damage, whereas red implies extremely damaged places

7.5.7 Damage localizer results

Each of the three detection methods separately provides interesting outputs, but it is their connection that makes the resulting application so notable. Thanks to the connection, very satisfactory results have been achieved for locating the damaged areas (Figures 7.37 and 7.38).

Table 7.5 Rejected and accepted samples

	FAR	FRR	F1	ACC
Acrodermatitis	0.1394	0.6667	0.1655	0.8347
Atopic eczema	0.1968	0.7021	0.4300	0.4533
Psoriasis	0.3408	0.7373	0.1956	0.5827
Verruca vulgaris	0.2329	0.5000	0.2073	0.7496

Table 7.6 Classifier accuracy measures

	TP	FN	FP	TN
Acrodermatitis	12	18	103	478
Atopic eczema	134	289	25	163
Verruca vulgaris	23	17	314	257
Total	611	611	611	611

7.5.8 Classifier accuracy

The classifier itself is ready to be further extended and improved. It relies on the detection results. So far, the following accuracy measures have been computed: FAR (*false accept rate*) and FRR (*false reject rate*) [20], ACC (*accuracy*) and F1 score [20]—see Table 7.5. A total of 611 fingerprint images from dactyloscopic cards from the database were used for the test. Table 7.6 shows the numbers of fingerprint images that were correctly/incorrectly classified. TP (*true positives*) = number of positives that were correctly accepted, FN (*false negatives*) = number of negatives that were incorrectly rejected, FP (*false positives*) = number of positives that were incorrectly accepted and TN (*true negatives*) = number of negatives that were correctly rejected.

The classification accuracy reached high values for acrodermatitis (83.5%) and verruca vulgaris recognition (75.0%), whereas it was lower for atopic eczema (45.3%) and psoriasis (58.3%). Better performance could be gained by improving the classification decision rules, as well as coming up with new types of features detection.

7.6 Conclusion

This chapter includes a description of fingerprints which are common in a population, however, cause big troubles in automatic processing and recognition. In the past, we did a lot of acquisition tests of problematic fingerprints, including acquirement of a database with diseased fingerprints. Furthermore, we invested our effort to development of algorithms for detection of various troubles in fingerprints.

Before the methods were designed, the faculty's database of fingerprint images affected by skin disease was thoroughly analyzed and, based on this foundation, possible algorithms for damaged area detection were tested, including the Hough

detection for lines and circles, which was rejected for its inaccuracy. In the end, the following methods were implemented: detection from block orientation field, histogram analysis method and the flood fill method. The best results were achieved by connecting the methods together using a special data structure, StatusMap.

The classifier makes decisions based on statistics that resulted from testing the algorithms on the whole fingerprint database. Using the methods described in this work, the program reached an accuracy of 83.5% for acrodermatitis, 45.3% for atopic eczema, 58.3% for psoriasis and 75.0% for verruca vulgaris.

The resulting program is a graphical user interface (GUI) application that enables the user to load an image, adjust the processing pipeline and view and save the results. It can be used as an analytical tool for future researchers.

There is a great potential for improvements and enhancements, and it is assumed that the research will continue. There are opportunities for the results of this research to be used in real-life applications in the future, such as medical applications or programs for police and security purposes.

At the moment, we work on algorithms for detection of concrete troubles in fingerprints and other skin diseases. Furthermore, we work on development of algorithms for simulation of diseases and damages into synthetic fingerprints.

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