Chapter 12

Influence of Skin Diseases on Fingerprint Quality and Recognition

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Additional information is available at the end of the chapter

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1. Introduction

Fingerprint recognition belongs to one of the most often used biometric technologies worldwide. It is believed that fingerprints could be used for the recognition of a person in nearly any case; however there exist many cases, where the fingerprint recognition could not be used. There exist some influencing factors [1] that have an impact to the process of fingerprint recognition, e.g. the environmental influences, dirtiness on finger or the sensor, electromagnetic radiation or diseases. This chapter deals with the circumstances which influence the quality of fingerprints – we are limited on skin diseases here, further we explain how we can evaluate the quality of the acquired fingerprint.

The fingerprint recognition consists of five main steps (see Fig. 1) [2, 3, 4]:

- *Fingerprint acquirement* – the fingerprint is scanned using a sensor (for sensor technologies see [1]), i.e. the physical human biometric attribute is digitized and transferred to the computer.
- *Image enhancement* – this step is very important for further processing, because the quality of the fingerprint image could be enhanced here. There are several methods used for image quality enhancement – edge filters, filtering in frequency spectrum (after Fast Fourier Transform), Gabor filter, etc.
- *Thresholding* – the image is normally acquired with 256 gray levels, but we need a binary representation. Using various thresholding schemes (e.g. adaptive thresholding or regional average thresholding), it is possible to separate papillary lines (ridges) from background (valleys).

- *Thinning* or *Skeletization* – the papillary lines from the previous step have varying thickness. To make the algorithm for minutiae extraction as simple as possible, we prefer the thickness of all papillary lines in all parts having only one pixel.
- *Minutiae extraction* – this algorithm detects and extracts all minutiae found in the fingerprint. We distinguish between minutiae in verification systems (here are generally used 2 minutiae – ridge ending and bifurcation [2]) and identification (dactyloscopic) systems [5], where many special minutiae are used.

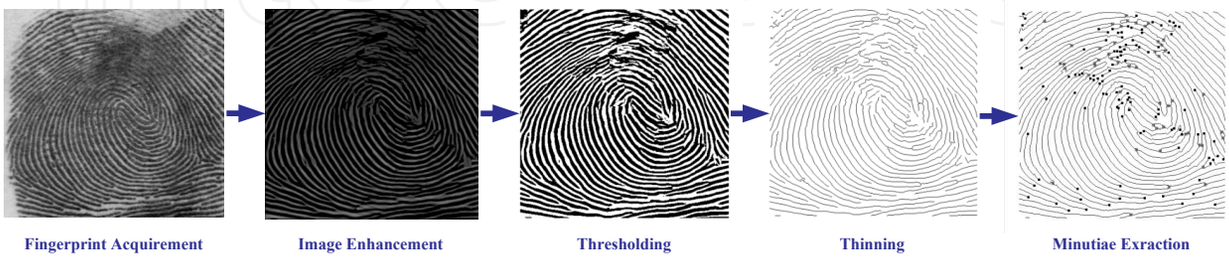

Figure 1. An overview of the fingerprint recognition.

The fingerprint recognition technology is well accepted in our society [6]. Fingerprints could be used not only for the known user verification / identification tasks, but also e.g. for cryptographic key generation [7, 8, 9, 10], computerized patient record [11] or for use with credit cards [12] etc. Anyway, the influence of skin diseases to fingerprint recognition in biometric systems has not been discussed sufficiently till today, therefore we hope that this chapter brings you closer information to this topic.

In the chapter 2, the categorization into three groups of skin diseases is done and the most important diseases in each group are briefly described. The chapter 3 describes how these skin diseases could influence the process of automatic fingerprint recognition. Chapters 4 and 5 deal with fingerprint image enhancement and estimation of their quality.

2. Skin diseases

Skin diseases represent very important, but often neglected factor of the fingerprint acquirement. It is impossible to say in general how many people suffer from skin diseases, because there are so many various skin diseases [4]. In a general medical practice about 20-25% of patients with skin complaints are referred. When discussing whether the fingerprint recognition technology is a perfect solution capable to resolve all our security problems, we should always keep in mind those potential users who suffer from some skin disease.

In the following text, several skin diseases, which attack hand palms and fingertips, are introduced from the medical point of view.

The situation after 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 dis-

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ease has attacked and destroyed the structure of papillary lines in the epidermis and underlying dermis (top two layers of the skin), the papillary lines will not grow in the same form as before (if at all) and therefore such user could be restricted in their future life by being excluded from the use of fingerprint recognition systems, though their fingers do not have any symptoms of the skin disease anymore.

Skin makes up to 12-15% of an adult's body weight. Each square centimeter has 6 million cells, 5,000 sensory points, 100 sweat glands and 15 sebaceous glands. It consists of three layers [18]: *epidermis* (the outer layer), *dermis* and *subcutaneous* (fat) layer.

Skin is constantly being regenerated. A keratinocyte („skin cell") starts its life at the lower layer of epidermis (the basal layer), which is nourished by blood vessels and is supplied with nerve endings from dermis. The cell migrates upward from basal layer to stratum corneum (the outermost skin layer). During four weeks the cell undergoes a series of changes, gradually flattening out and moving toward the surface. Then it dies and is shed. The epidermis is not supplied with blood vessels, but has nerve endings. The shape of dermoepidermal junction basically forms the structure of papillary lines.

There are several skin functions [19]:

- *Sensation* – the nerve endings in the skin identify touch, heat, cold, pain and light pressure.
- *Heat regulation* – the 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. anti-smoking 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".
- *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.

There are a lot of skin diseases, which can affect palms and fingers. We find plenty of skin diseases including description of their influence on the structure and color of the skin in specialized medical literature, e.g. [16]. In the following subchapters we describe some of these diseases together with photographs. These clearly show that these diseases may cause many problems in automatic biometric systems.

The fingerprint recognition systems are usually used only for adults. There is almost no information from appropriate tests with children. Although we know that papillary lines emerge on infant's fingers already in the mother's uterus [24], i.e. we might be able to recognize the fingerprints of infants, the common fingerprint recognition systems are suitable for adults only (due to the area and resolution of fingerprint sensors, etc.). It should not be forgotten that a skin disease in early childhood could have an influence on the skin in adult years (example is *incontinentia pigmenti* [25] on a small child hand), i.e. there could be some problems with fingerprint acquirement caused by such skin disease in a young age.

The subcategory of skin diseases affecting only the skin color are the least dangerous for the quality of the fingerprint image. In fact, only one fingerprint technology can be considered as sensitive to such diseases – the optical technology [26], but if FTIR-based optical sensors are used, the change of skin color may have no influence on the quality of the resulting images. The case of the other two subcategories (influence of skin structure and combination of influence of skin color and structure) is different. If the structure of papillary lines has changed, it is often impossible to recognize the original curvatures of papillary lines and therefore it is impossible to decide whether the claimed identity is the user's identity. Unfortunately, there are many such skin diseases which attack papillary line structure. Nearly all sensor technologies, namely optical, capacitive, e-field, electro-optical, pressure sensitive and thermal are exposed to such risk [26]. Only one sensor technology is missing here – the ultrasound technology. This technology has an advantage: the ultrasound waves can penetrate under the upper skin layer to the curvatures in dermoepidermal junction forming the papillary lines structures and therefore it might be possible to reconstruct the real fingerprint image, but only if the disease has not attacked this underlying structure. If yes, there is no chance to get an original papillary lines structure.

The situation after 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 papillary lines in dermoepidermal junction, the papillary lines will not grow in the same form as before (if at all) and therefore such user could be restricted in his/her future life by being excluded from the use of fingerprint recognition systems, though his fingers don't have any symptoms of a skin disease any more.

2.1. Diseases causing histopathological changes of epidermis and dermis

These diseases may cause problems for the most types of sensors, because color of the skin and structure of epidermis and dermis are influenced.

Hand eczema [17] is an inflammatory non-infectious long-lasting disease with relapsing course. It is one of the most common problems encountered by the dermatologist. Hand dermatitis causes discomfort and embarrassment and, because of its locations, interferes significantly with normal daily activities. Hand dermatitis is common in industrial occupations. The prevalence of hand eczema was approximately 5.4% and was twice as common in females as in males. The most common type of hand eczema was irritant contact dermatitis (35%), followed by atopic eczema (22%), and allergic contact dermatitis (19%). The most common contact allergies were to nickel, cobalt, fragnance mix, balsam of Peru, and colo-

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phony. Hand eczema was more common among people reporting occupational exposure. The most harmful exposure was to chemicals, water and detergents, dust, and dry dirt.

Fingertip eczema [17] is very dry, chronic form of eczema of the palmar surface of the fingertips, it may be result of an allergic reaction or may occur in children and adults as an isolated phenomenon of unknown cause. One finger or several fingers may be involved. Initially the skin may be moist and then become dry, cracked, and scaly. The skin peels from the fingertips distally, exposing a very dry, red, cracked, fissured, tender, or painful surface without skin lines – see Figure 2.

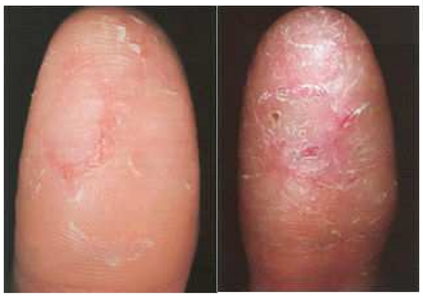

Figure 2. Fingertip eczema [17].

Pomfolyx (dishydrosis) [16] is a distinctive reaction pattern of unknown etiology presenting as symmetric vesicular hand and foot dermatitis. Itching precedes the appearance of vesicles on the palms and sides of the fingers. The skin may be red and wet. The vesicles slowly resolve and are replaced by rings of scale. Chronic eczematous changes with erythema, scaling, and lichenification may follow.

Tinea of the palm [17] is dry, diffuse, keratotic form of tinea. The dry keratotic form may be asymptomatic and the patient may be unaware of the infection, attributing the dry, thick, scaly surface to hard physical labor. It is frequently seen in association with tineapedis which prevalence is 10 to 30%.

Pyoderma [22] is a sign of bacterial infection of the skin. It is caused by *Staphylococcus aureus* and *Streptococcus pyogenes*. Some people are more susceptible to these diseases (such as diabetics, alcoholics, etc.) – see Figure 3.

Figure 3. Abscess on finger of patient with diabetes [16] and pyoderma [23].

Pitted keratolysis [17] is a disease mimicking tinea, especially for people who swelter and wear rubber gloves in the hot, humid environment. Hyperhydrosis is the most frequently observed symptom. The disease is bacterial in origin, characterized by many circular or longitudinal, punched out depressions in the skin surface. The eruption is limited to the stratum corneum.

Keratolysis exfoliativa [17] is a common, chronic, asymptomatic, non-inflamatory, bilateral peeling of the palms of the hands. Its cause is unknown. The eruption is most common during the summer months and is often associated with sweaty palms and soles. It is characterized by scaling and peeling, the central area becomes slightly red and tender.

Lichen planus [22] is quite common, unique inflammatory cutaneous and mucous membrane reaction pattern of unknown etiology. LP of the palm and soles generally occurs as an isolated phenomenon. The lesions are papules aggregated into semitranslucent plaques with globular waxy surface, ulceration may occur.

Acanthosis nigricans [16] is non-specific reaction pattern that may accompany obesity, diabetes, tumors. AN is classified into benign and malignant forms. In all cases the disease presents with symmetric, brown thickening of the skin. During the process there is papillary hypertrophy, hyperkeratosis, and increased number of melanocytes in the epidermis.

Pyogenic granuloma [17] is a benign acquired vascular lesion of the skin that is common in children and young adults. It often appears as a response to an injury or hormonal factors. Lesions are small rapidly growing, yellow-to-bright red, dome-shaped.

Systemic sclerosis [20] is a chronic autoimmune disease characterized by sclerosis of the skin or other organs. Emergence of acrosclerosis is decisive for fingerprinting. Initially the skin is infused with edema mainly affecting hands. With the progressive edema stiff skin appears and necrosis of fingers may form. The disease leads to sclerodactyly with contractures of the fingers. For more than 90% of patients is typical Raynaud's phenomenon (see below). The typical patient is a woman over 50 years of age.

Raynaud's phenomenon[17] represents an episodic vasoconstriction of the digital arteries and arterioles that is precipitated by cold and stress. It is much more common in women. There are three stages during a single episode: pallor (white), cyanosis (blue), and hyperemia (red).

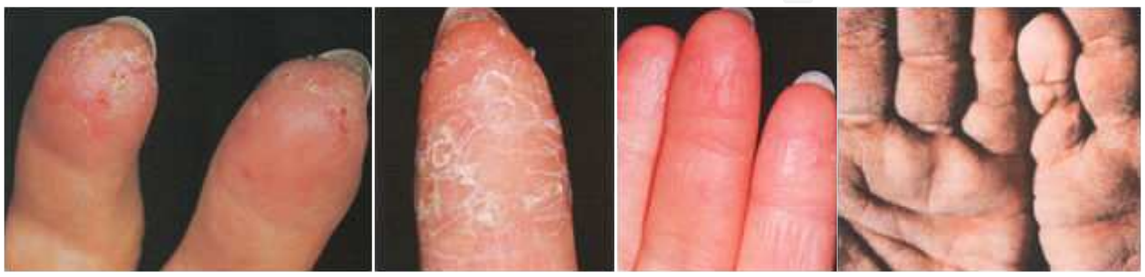

Figure 4. Different types of eczema [17] (3× left) and acanthosis nigricans [16] (right).

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Drug induced skin reactions [17] are among the most common adverse drug reactions. They occur in many forms and can mimic virtually any dermatosis. Occur in 2-3% of hospitalized patients. Sulfonamides, NSAIDs and anticonvulsants are most often applied in the etiology.

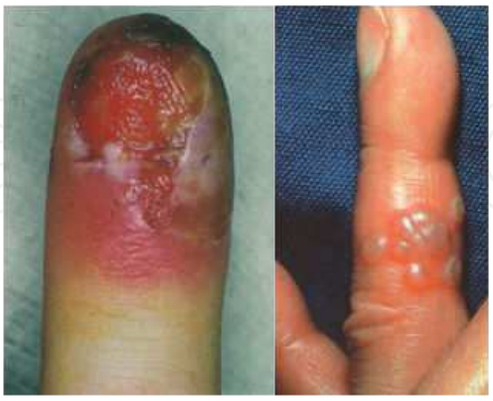

Figure 5. Herpes simplex virus:patient with HIV (left) [20]; deepseated blisters (right) [16].

Herpes simplex virus [16] in the host with systemic immune-compromise may cause chronic ulcerations as you can see by patient with advanced HIV disease in Figure 5 (left).

Herpetic infection may uncommonly occur on the fingers or periungually. Lesions begin with tenderness and erythema and deepseated blisters develop 24 to 48 hours after symptoms begin (see Figure 5, right).

Scabies [21] is highly contagious disease caused by the mite *Sarcoptes scabiei*. It is characterized by red papules, vesicles and crusts located usually on the areas with tender skin, palms and soles especially in infants.

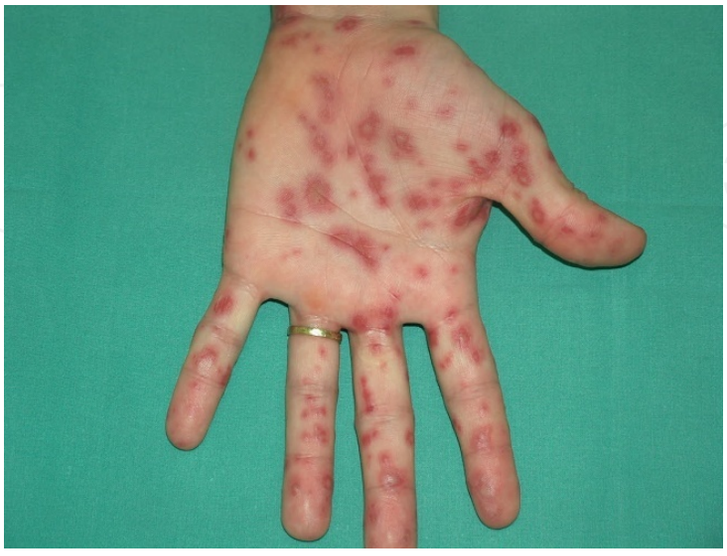

Figure 6. Erythmea multiforme.

Erythema multiforme [22] is quite common skin disorder with multifactorial cause (see Figure 6). The most common triggering agents are infections (in the first place herpes virus) and drugs. Minor and major variant of this disease is described. Both forms are characterized by erythematous target-shaped lesions with a center with hemorrhage, blistering, necrosis or crust. When the trigger is herpetic infection, frequent recurrences come.

Dermatitis artifacta [25] are changes of skin due to the manipulation by patient. Patients often have psychosomatic, psychiatric or drug abuse problems.

2.2. Diseases causing skin discoloration

Hand, foot, and mouth disease (HFMD) [16] is contagious enteroviral infection occurring primarily in children and characterized by a vesicular palmoplantar eruption. The skin lesions begin as red macules that rapidly become pale, white, oval vesicles with red areola.

Xantomas [17] are lipid deposits in the skin and tendons that occur secondary to a lipid abnormality. These localized deposits are yellow and are frequently very firm.

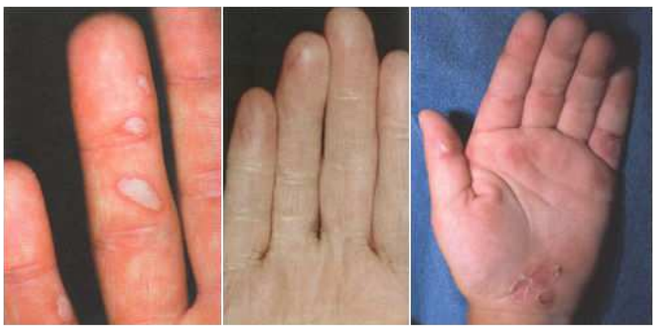

Figure 7. Hand, foot and mouth syndrome[16]; xantomas [20]; epidermolysis bullosa [21].

Scarlet fever (scarlatina) [17] is contagious disease produced by streptococcal, erythrogenic toxin. It is most common in children (ages 1 to 10 years). In the ending stages of the disease large sheats of epidermis may be shed from the palms in glovelike cast, exposing new tender and red epidermis beneath.

Kawasaki's disease [20] is an acute febrile illness of infants and children, characterized by cutaneous and mucosal erythema and edema with subsequent desquamation, cervical lymphadenitis, and complicated by coronary artery aneurysms (20%). Most cases of Kawasaki's disease in adults represent toxic shock syndrome. Erytematous macules appear 1 to 3 days after onset of fever, enlarge and become more numerous, then desquamation beginning on tips of fingers is highly characteristic.

Secondary syphilis [20]is characterized by mucocutaneous lesions, which may assume a variety of shapes, including round, elliptic, or annular. The color is characteristic, resembling a „clean-cut ham" or having a copery tint.

Carotenosis [16] is yellowish discoloration of the skin, especially of the palms and soles that is sometimes seen in diabetic patients.

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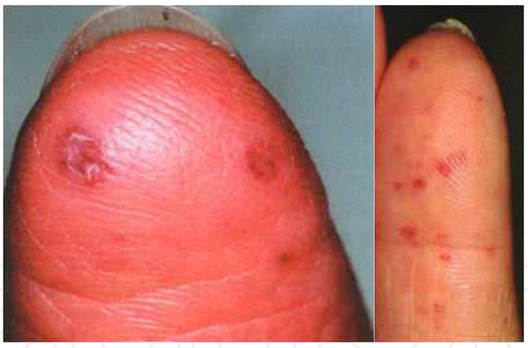

Figure 8. Hereditary hemorrhagic teleangiectasia [16].

Hereditary hemorrhagic teleangiectasia [20] is an autosomal dominant condition affecting blood vessels, especially in the mucous membranes of the mouth and the gastrointestinal tract. The diagnostic lesions are small, pulsating, macular and papular, usually punctuate. Teleangiectases are present on different parts of the body, palms and soles including (see Figure 8).

2.3. Diseases causing histopathological changes in junction of epidermis and dermis

These diseases are focused mainly on ultrasonic sensors, which detect the base of papillary lines on the border of epidermis and dermis. The diagnoses also belong to the first group.

Hand eczema – particularly chronic forms (see above).

Warts (verruca vulgaris) [22] are 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.

Psoriasis [20] is characterized by scaly papules and plaques. It occurs in 1% to 3% of the population. The disease is transmitted genetically; environmental factors are needed to precipitate the disease. The disease is lifelong and characterized by chronic, recurrent exacerbations and remissions that are emotionally and physically debilitating. Psoriasis of the palms and fingertips is characterized by red plaques with thick brown scale and may be indistinguishable from chronic eczema.

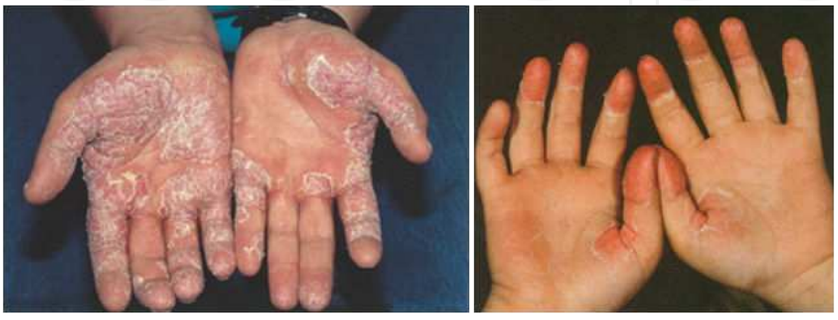

Figure 9. Psoriasis (left) [21]; scarlet fever (right) [17].

Systemic lupus erytematosus (SLE) [17] is a multisystem disease of unknown origin characterized by production of numerous diverse of antibodies that cause several combinations of clinical signs, symptoms and laboratory abnormalities. The prevalence of LE in North America and northern Europe is about 40 per 100,000 population. In the case of acute cutaneous LE indurated erythematous lesions may be presented on palms.

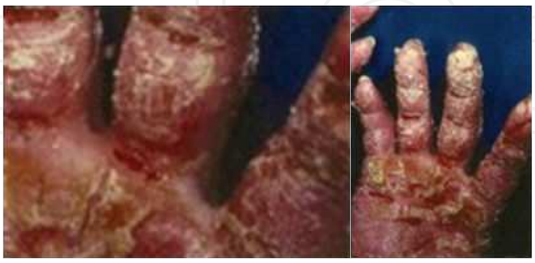

Figure 10. Psoriasis vulgaris [23].

Epidermolysis bullosa [20] is a term given to groups of genetic diseases in which minor trauma causes non-inflammatory blistering (mechanobullosus diseases). Repetitive trauma may lead to a mitten-like deformity with digits encased in an epidermal „cocoon". These diseases are classified as scarring and non-scarring and histologically by the level of blister formation. Approximately 50 epidermolysis cases occur per million live births in the United States.

3. Influence of skin diseases to fingerprint pattern

The process of analysis and further elimination of influence of dermatologic diseases to fingerprint recognition process begins with analysis of influence to the fingerprint pattern. Image of fingerprint pattern can be obtained either by classic manual way using dactyloscopic card and special ink or using the electronic sensors. Both ways have their advantages and disadvantages and both of them could have been influenced by skin diseases in different ways. It will be necessary to analyze the influence on both of these capturing methods.

3.1. Ability of fingerprint scanners to scan a finger distorted by skin disease

For acquiring the digital image of a fingerprint pattern in the most cases the so called fingerprint scanners are used. These scanners are called "live-scan" fingerprint capture devices [28]. This term reflexes the fact that these sensors cannot be used for latent fingerprint scanning and for the scanning the live finger is needed. These scanners can be divided into several groups upon their sensing technology [4, 27, 28] – see the following subchapters

3.1.1. Optical fingerprint scanners

Basic principle of optical fingerprint scanners works in the following way: finger is placed on the sensor platen and it's illuminated by a light source. The pattern of fingerprint papil-

lary lines is then captured by an integrated CCD or CMOS camera. The oldest and most commonly used type of optical fingerprint scanner is the type which uses the Frustrated Total Internal Reflection (FTIR) for the fingerprint image acquisition.

There also exist models which use another image acquisition techniques like FTIR technique with sheet prism made of a number of prismlets adjacent to each other instead of a single large prism or a model which uses optical fibers [28].

3.1.2. 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. By placing the finger on sensor surface, each small plate and the corresponding part of skin over it start behave like a micro-capacitor. By measuring the small electrical charges between plates and finger, it is possible to reconstruct the profile of papillary lines ridges and valleys and thus to reconstruct the fingerprint image.

3.1.3. Thermal fingerprint scanners

Thermal fingerprint scanners contain special, so called pyro-electric cell which detects the thermal changes and converts them into an electrical charge. The main idea is that fingerprint papillary line ridges produce a higher temperature differential to the valleys. The temperature difference produces an image when a contact occurs, but this image soon disappears because the thermal equilibrium is quickly reached and the pixel temperature is stabilized [28]. Therefore the thermal sensors are usually made in sweep variant in which this disappearing problem does not occur.

3.1.4. Pressure fingerprint scanners

Pressure fingerprint scanners are made from two parallel electro-conductive layers with non/conductive gel between them. Ridges of papillary lines unlike the valleys by pressing the first flexible conductive layer create the contact of these two conductive layers. The conductive layers are in contact only in sensor parts where papillary line ridges are. By measuring the electrical charge between connected layers, it is possible to reconstruct the original fingerprint image.

3.1.5. Electro-optical fingerprint scanners

Electro-optical scanners contain two layers. First layer is made from a special polymer, which emits light when connected to the proper voltage [28]. Proper voltage can be obtained by contact with finger skin, which is conductive enough. Only the ridges are touching the polymer so on the other side of the polymer we could see light pattern of the fingerprint. The light pattern is than captured by the second layer, which is composed of an array of photodiodes.

3.1.6. E-field fingerprint scanners

The sensor consists of a drive ring that generates an RF (radio frequency) sinusoidal signal and a matrix of active antennas that receives a very small amplitude signal transmitted by the drive ring and modulated by the derma structure (subsurface of the finger skin) [28]. By analyzing the signal response received by antennas array, the reconstruction of fingerprint image is performed. The fingerprint pattern is acquired by simply measuring the electric field in subsurface of finger skin.

3.1.7. Ultrasonic fingerprint scanners

Ultrasonic scanners are based on sending acoustic signals toward the fingertip and capturing the response. The received response is analyzed and the fingerprint is reconstructed.

3.2. Creation of station for diseased fingerprint capturing

For analyzing the influence of skin diseases on the process of fingerprint recognition it will be necessary for the capturing station to contain as much dactyloscopic sensors as possible, ideally each of them based on different scanning technology. It is also presumable that some very invasive skin disease deforms the fingerprint pattern in a way that no connected sensor will be able to scan this fingerprint. For these situations the capturing station has to be equipped with tools for manual dactyloscopic fingerprinting. Another significant and inseparable part of capturing station creation process is creation of capturing application. This capturing application has to be able to communicate with all connected sensors and to fast fingerprint capturing of all patient's fingers. The capturing station should also contain some device for affected finger photo-documentation like camera, video-camera or digital microscope. This device should also be controllable by the capturing application.

The final version of capturing station consists of the following components:

- laptop and its accessories
- capturing application installed on laptop
- set of electronic dactyloscopic sensors
- dactyloscopic card and special ink
- digital microscope
- laboratory stand with boss and clamp for microscope

Due to available financial, technological and implementation resources the following dactyloscopic scanners were chosen: **Sagem MSO 300** (optical touch), **UPEK EikonTouch 500** (capacitive touch), **UPEK Eikon II Fingerprint Reader** (capacitive sweep), **TBS 3D Enroll Series 2011** (touchless optical multispectral) and the **digital microscope DinoLite Pro.**

After obtaining all necessary hardware the next step was to design and implement the capturing application. During the design and implementation process the following requirements had to be considered:

http://dx.doi.org/10.5772/51992

- application has to be able to communicate with all connected sensors and with connected digital microscope,
- application has to contain united and practical interface for easy and fast capturing of multiple samples of each patients of the affected finger by each dactyloscopic sensor,
- application has to contain controls for entering the patients diagnosis by a doctor.

The newest version of capturing application also contains full multi-language support including runtime dynamic language switching. At the moment, the application supports Czech, English and German languages.

The first created station is installed in Faculty Hospital in Olomouc in the Czech Republic. The capturing is performed by a medical specialist from the Dermatologic and Venerologic Clinic at the Palacky University and Faculty Hospital in Olomouc. In the nearest future the process of the second station creation will be finished and the second station (see Fig. 11) will be installed at a dermatologist in Darmstadt, Germany.

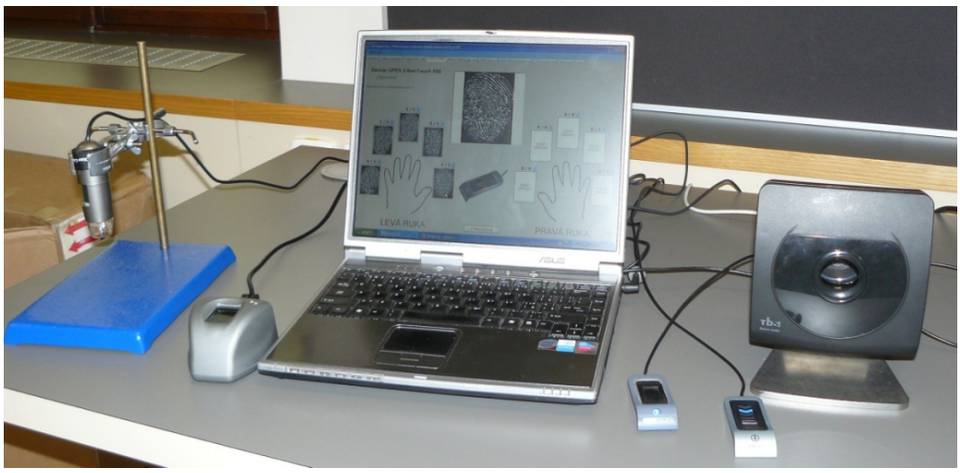

Figure 11. Second version of the capturing station.

3.3. Creation of suitable database of diseased fingerprints

Very significant and inseparable part of skin diseases influence analysis plays the process of suitable testing data acquirement. By these data it is meant a database of fingerprints affected and influenced by at least one of various dermatologic diseases. Having done the database acquirement it will be possible to analyze the influence of specific skin diseases and/or test the designed and implemented correction algorithms.

Obtaining a high quality biometric database usually is a long time consuming task which demands a big amount of patience. Biometric algorithms cannot be tested only on few samples from a small group of individuals of similar age and employment like research colleagues. High quality biometric database has to contain samples from wide spectrum of individuals categorized by all factors which may have influence on reason for which the da-

tabase is acquired. Also there has to be enough samples in each of such category. For example the ideal database of fingerprints has to contain enough fingerprints of men and women of all age groups and such database should also contain so called critical samples, i.e. samples from individuals whose job or hobby affects their fingerprint pattern like mountain climbers or people working with chemicals.

For our developing and testing purposes it is necessary to create a database of fingerprints affected by a dermatologic disease. In the presence there exists no such special database so it will be necessary to create a new and first one. The most promising and reliable sources of such data are dermatological departments in hospital. It is also necessary to agree cooperation with dermatological specialists from such departments which will be willing to scan theirs patient's fingerprints and to provide reliable diagnosis of the scanned disease. For the purpose of database categorization the following factors are considered and recorded: age, gender, job and kind of dermatologic disease.

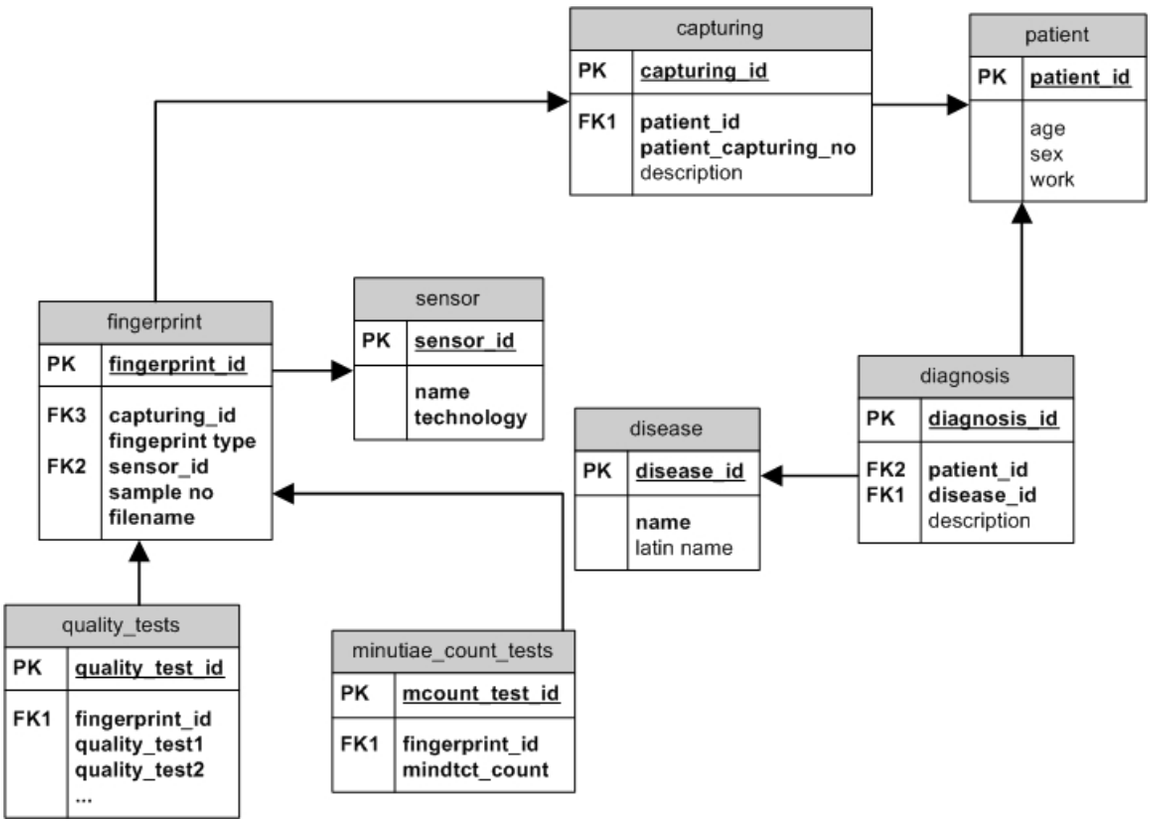

Figure 12. ER diagram of current diseased fingerprint database.

Current version of the database contains 594 fingerprints of 19 different patients. These amounts are from the first acquired set from the hospital in Olomouc. There are two more sets of fingerprints but they were not processed yet. The real number of fingerprints in our database is two or three times higher. In Figure 12 you can see the entity relationship diagram of actual version of database. The database contains fingerprints of eleven different

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dermatologic diseases. The most common and typical that are present in the database are: light atopic eczema, advanced atopic eczema, verruca vulgaris, psoriasis and cut wound. The last sample does not belong to the dermatologic diseases it is related to them because it can negatively affect the process of fingerprint recognition.

In Figures 13 to 17 we show several samples of acquired fingerprints. Each set of fingerprints begins with photography of the affected finger from the digital microscope and fingerprints made manually by using the dactyloscopic card and ink. After them there are fingerprints from electronic sensors if the sensor capturing was successful.

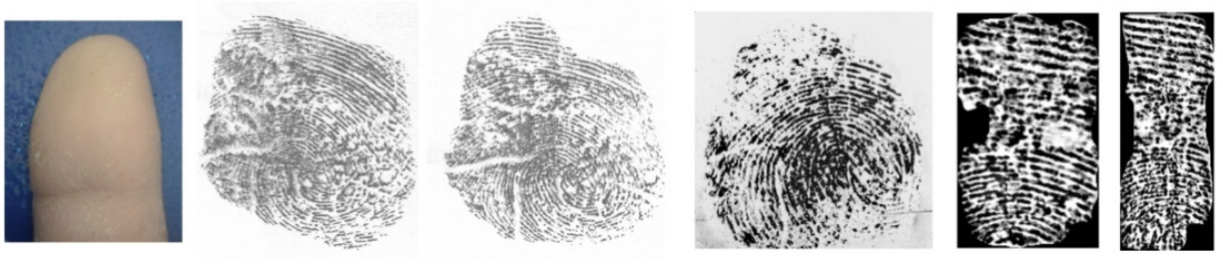

Figure 13. Light atopic eczema – influence on fingerprints.

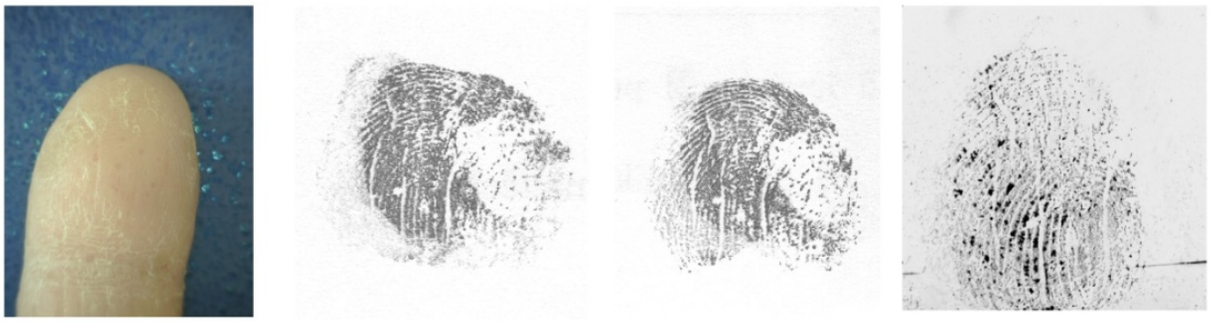

Figure 14. Advanced atopic eczema – influence on fingerprints.

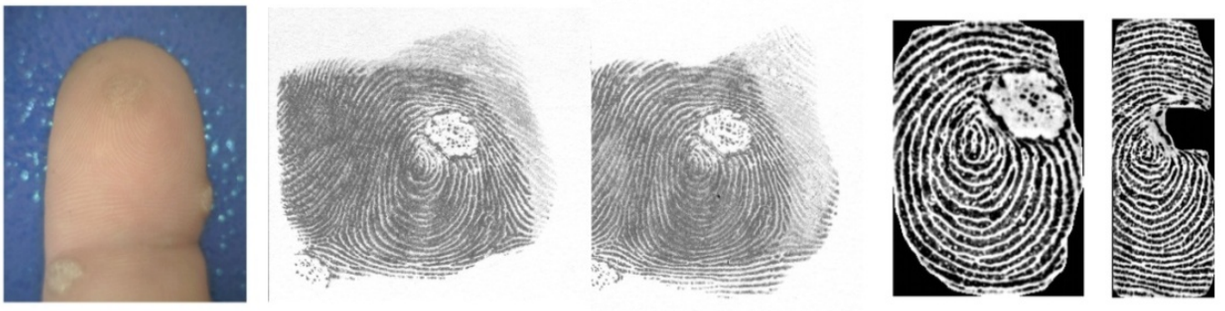

Figure 15. Verruca vulgaris – influence on fingerprints.

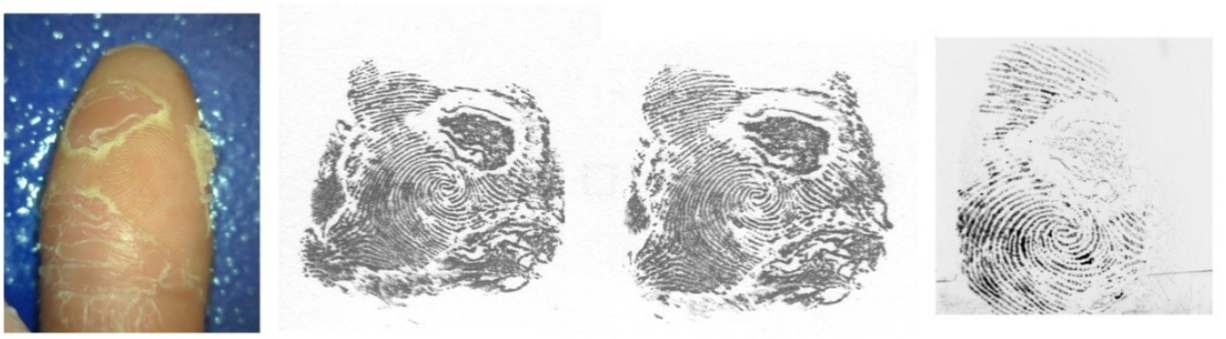

Figure 16. Psoriasis – influence on fingerprints.

Figure 17. Cut wound – influence on fingerprints.

4. Fingerprint image enhancement algorithm

Currently the most widely used and the most accurate automatic fingerprint verification/identification techniques use minutiae-based automatic fingerprint matching algorithms. Reliably extracting minutiae from the input fingerprint images is critical to fingerprint matching. The performance of current minutiae extraction algorithms depends heavily on the quality of input fingerprint images [29]. In an ideal fingerprint image, ridges and valleys alternate and flow in a locally constant direction and minutiae are anomalies of ridges. In practice, due to variations in impression conditions, ridge configurations, skin conditions (dryness, moist finger, aberrant formations in epidermal ridges of fingerprints, postnatal marks, occupational marks, skin diseases), acquisition devices, and non-cooperative attitudes of subjects, etc., a significant percentage of acquired fingerprint images (approximately 10% according to [29]) is of a poor quality. The ridge structures in poor-quality fingerprint images are not always well defined and hence they cannot be always correctly detected. This could result in failures of minutiae extraction algorithms; a significant number of spurious minutiae may be created, a large percentage of genuine minutiae may be undetected, and a significant amount of error in position and orientation may be introduced.

To ensure that the performance of the minutiae extraction algorithms is robust with respect to the quality of input fingerprint images, an *enhancement algorithm* [42], which can improve

http://dx.doi.org/10.5772/51992

the quality of the ridge structures of input fingerprint images, is thus necessary. Generally, for a given fingerprint image, fingerprint regions can be assigned to one of the following three categories (Fig. 18) [29]:

- *Well-defined regions*, in which ridges and furrows are clearly visible for a minutia extraction algorithm to operate reliably.
- *Recoverable corrupted regions*, in which ridges and furrows are corrupted by a small amount of creases, smudges, etc. But they can still be correctly recovered by an enhancement algorithm.
- *Unrecoverable corrupted regions*, in which ridges and furrows are corrupted by such a severe amount of noise and distortion that it is impossible to recover them.

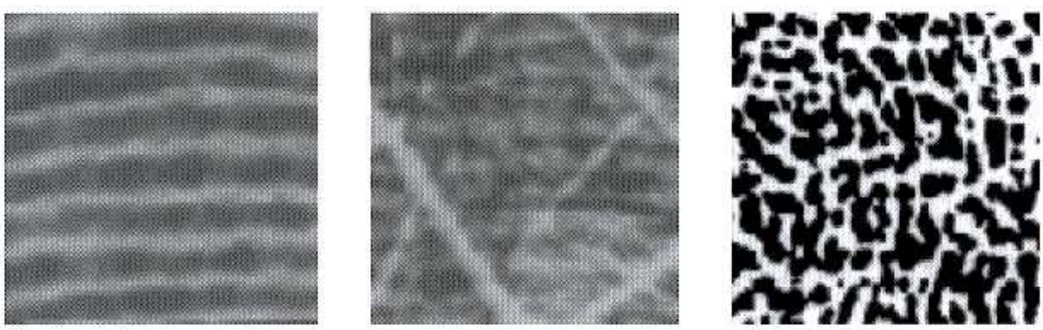

Figure 18. Examples of fingerprint regions [29]: a) Well-defined region (left); b) Recoverable region (middle); c) Unrecoverable region (right).

The interoperability among sensors from different vendors, or using different sensing technologies, plays a relevant role. The resulting images from different technologies vary very much in the representation of the grayscale levels, sharpness of valleys and ridges and resolution. Fortunately, it is often possible to compensate these factors to achieve a good interoperability among such sensors, e.g. see [30].

Based on filtering domains, most fingerprint enhancement schemes can be roughly classified using two major approaches [31]: *spatial-domain and frequency-domain*. The filtering in a spatial-domain applies a convolution directly to the fingerprint image. On the other hand, the filtering in a frequency-domain needs the Fourier analysis and synthesis. Thus a fingerprint image is transformed than multiplied by filter coefficients and in the end inverse-transformed by Fourier coefficients back to an enhanced fingerprint image. In fact, if the employed filters are the same, enhancement results from both domains should be exactly the same according to the signal processing theorem. However, in a practical implementation, these two approaches are different in terms of enhancement quality and computational complexity of algorithms.

In the following subchapters, some important and often used fingerprint enhancement methods will be introduced. Nevertheless, the list of such methods cannot be complete, as the amount of such methods exceeds the scope and possibilities of this chapter.

4.1.1. Spatial domain filtering algorithm

The *spatial domain filtering algorithm* [29] adaptively enhances the clarity of ridge and valley structures using a bank of Gabor filters (see below) that are tuned to the local ridge orientation and ridge frequency. The local ridge orientation and ridge frequency are estimated directly from input images in the spatial domain.

A 2D Gabor filter [32] can be thought of as a complex plane wave modulated by a 2D Gaussian envelope [33]. These filters optimally capture both the local orientation and frequency information and their development has been initiated by observing the linear response of the receptive field in simple striate cortex cells. By tuning a Gabor filter to a specific frequency and direction, the local frequency and orientation information can be obtained. Thus, they are well suited for extracting the texture information from images.

An even symmetric Gabor filter has the following general form in the spatial domain [33]:

$$G_{\theta,f}(x,y) = e^{-\frac{1}{2}\left[\frac{x'^2}{\delta_x^2}+\frac{y'^2}{\delta_y^2}\right]}\cos(2\pi f x') \tag{1}$$

$$\text{and } x' = x\sin\theta + y\cos\theta,\ \ y' = x\cos\theta - y\sin\theta \tag{2}$$

where f is the frequency of the sinusoidal plane wave at the angle θ with the x-axis, and δ_x and δ_y are the standard deviations of the Gaussian envelope along the x and y axes, respectively.

The main steps of the enhancement algorithm are shown in Fig. 19 and are listed below [29]:

- *Normalization*. An input image needs to be normalized so that it has a pre-specified mean and variance. The normalization is a pixel-wise operation, in which an output pixel value depends only on the corresponding input pixel. It does not change the clarity of the ridge and valley structures. The main purpose of normalization is to reduce the variations in gray-level values along ridges and valleys what facilitates the subsequent steps.
- *Local ridge orientation estimation*. The local orientation indicates the major ridge orientation tendency in a local neighborhood. It represents an intrinsic property of a fingerprint image and defines an invariant coordinate for ridges and valleys in a local neighborhood. In neighboring ridges, the local ridge orientation changes slowly. Therefore, it is usually a specified block-wise property. In addition, there is no difference between a local ridge orientation of 90° and 270°, since the ridges oriented at 90° and the ridges oriented at 270° in a local neighborhood cannot be differentiated from each other.
- *Local ridge frequency estimation*. Local ridge frequency is the frequency of the ridge and valley structures in a local neighborhood along a direction normal to the local ridge orientation. The ridge and valley structures in a local neighborhood, where minutiae or singular points appear, do not form a well-defined sinusoidal-shaped wave. In such situations, the

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frequency is defined as the average frequency in the neighborhood. The local ridge frequency represents another intrinsic property of a fingerprint image.

- *Estimation of region mask*. The region mask is used to indicate the category of pixels. A pixel could be either a non-ridge-and-valley (unrecoverable) pixel or a ridge-and-valley (recoverable) pixel. A pixel (or a block of pixels) in an input fingerprint image could be either in a recoverable region or in an unrecoverable region. The classification of pixels into recoverable and unrecoverable categories can be performed based on the assessment of the shape of the wave formed by local ridges and valleys.
- Filtering. A bank of Gabor filters tuned to the local ridge orientation and ridge frequency is applied to the ridge-and-valley pixels in the normalized input fingerprint image to obtain an enhanced fingerprint image.

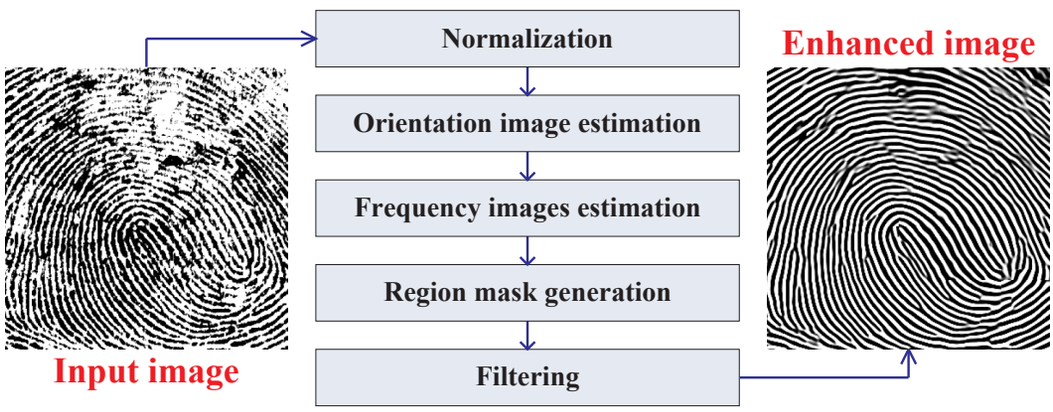

Figure 19. The flowchart of the spatial domain fingerprint enhancement algorithm [34].

4.1.2. Frequency domain filtering algorithm

The fingerprint enhancement approach in a frequency domain introduced in [31] consists of four concatenated processes: discrete cosine transform of sub-blocks of partitioning fingerprint, ridge orientation and frequency parameters estimation, filtering in DCT (*Discrete Cosine Transform*) domain and inverse discrete cosine transform of sub-blocks. The advantages of the proposed approach are as follows [31]:

- Fingerprint ridges form a natural sinusoid image – its spectrums are packed or localized in a frequency domain. Hence these spectrums can be easily shaped or filtered in this domain. Moreover, a filter can be specially designed in order to handle high curvature ridge area such as singular points. This is a great advantage over the spatial-domain filtering approach.
- When comparing with the discrete Fourier transform, the discrete cosine transform performs better in terms of energy compaction. Moreover, DCT coefficients are real numbers in comparison with complex numbers of discrete Fourier transform (DFT) coefficients. Therefore, we can handle DCT coefficients easier than DFT coefficients. Besides, the fast

DCT requires less computational complexity and less memory usage when comparing with the fast Fourier transform (FFT).

- By partitioning a fingerprint into sub-blocks, the proposed approach utilizes the spatially contextual information including the instantaneous frequency and orientation. Intrinsic features such as ridge frequency, ridge orientation, and angular bandwidth can be simply analyzed directly from DCT coefficients.

Conventional fingerprint enhancement schemes, when applied with non-overlapping blocks of partitioning fingerprint, often encounter blocking artifacts such as ridge discontinuities and spurious minutiae [31]. To preserve the ridge continuity and eliminate blocking artifacts, an overlapping block is applied to both DCT decomposition and reconstruction procedures. However, there is no need to apply any smooth spectral window for DCT because the overlapping area is large enough to prevent any blocking effects, corresponding with its energy compaction property.

4.1.3. Enhancement filtering in DCT domain

In the DCT domain, the filtering process is not simply the same as in the DFT domain [31] which required only the multiplication of coefficients. The Gabor filter is modified in order to cooperate with the DCT domain based on the Cartesian-form representation. The enhancement filtering in the DCT domain can be divided into two arithmetic manipulations, i.e. multiplication and convolution.

Filtering by Multiplication [31]: The enhancement filter can be expressed in terms of the product of separable Gaussian functions what is similar to the frequency-domain filtering technique [31]:

$$F_{fd}(\rho,\varphi) = F(\rho,\varphi)H_f(\rho)H_a(\varphi) \tag{3}$$

where $F(\varrho,\phi)$ are DCT coefficients in polar-form representation, directly related to DCT coefficients $F(u,v)$ in rectangular-form representation. $F_{\mathrm{fd}}(\varrho,\phi)$ are DCT coefficients of the filtering output. The $H_{\mathrm{f}}(\varrho)$ filter, which performs the ridge frequency filtering in Gaussian shape, is given by [31]:

$$H_f(\rho \mid \rho_0, \sigma_\rho, Z) = e^{-\frac{(\rho-\rho_0)^2}{2\sigma_\rho^2}}, \rho_0 = \sqrt{u_0^2 + v_0^2}, \quad \rho_{\min} \le \rho_0 \le \rho_{\max} \tag{4}$$

where ϱ_0 and σ_ϱ are the center of the high-peak frequency group and the filtering bandwidth parameter, respectively. The $\varrho_{\min}$ and $\varrho_{\max}$ parameters are minimum and maximum cut-off frequency constraints which suppress the effects of lower and higher frequencies such as ink, sweat gland holes or scratches in the fingerprint. Z is a filtering normalization factor depending on the filtering energy result.

http://dx.doi.org/10.5772/51992

The $H_d(\phi)$ filter, which performs the ridge orientation filtering, is given by [31]:

$$H_d(\varphi|\varphi_0,\sigma_\varphi,\varphi_{BW}) = \begin{cases} e^{-\frac{(\varphi-\varphi_0)^2}{2\sigma_\varphi^2}} & |\varphi-\varphi_0| \geq \varphi_{BW} \\ 1 & otherwise \end{cases} \quad (5)$$

where ϕ_0 is the peak orientation for the bandpass filter, σ_ϕ is the directional bandwidth parameter, and ϕ_{BW} is the angular bandwidth.

Filtering by Convolution [31]: Since θ and π-θ ridge orientation coefficients are projected into the same DCT domain region, both directional coefficients still remain from the previous filtering. In order to truncate inappropriate directional coefficients, two diagonal Gabor filters are exploited by the convolution operation. The finally enhanced DCT coefficients are given by [31]:

$$F_{enh}(u,v) = F_{fd}(u,v) * H_q(u,v) \quad (6)$$

where $F_{enh}(u,v)$ are enhanced DCT coefficients in rectangular-form, $F_{fd}(u,v)$ is the previous result of enhanced DCT coefficients in rectangular-form converted from $F_{fd}(\varrho,\phi)$ in polar-form. The quadrant correction filter, $H_q(u,v)$, is given by [31]:

$$H_q(u,v) = \begin{cases} \cos\left[\frac{(u+v)\pi}{2}\right] \cdot e^{-\frac{(u+v)^2}{2\sigma_q^2}} & \theta \geq \pi/2 \\ \cos\left[\frac{(u-v)\pi}{2}\right] \cdot e^{-\frac{(u-v)^2}{2\sigma_q^2}} & otherwise \end{cases} \quad (7)$$

where σ_q is the quadratic parameter and $\cos(n\pi/2)$ can attain only one of the three following values: -1, 0 or 1. Indeed, this convolution operation requires less computing because most of bandpass filtered coefficients are truncated to zero from the previous operation. In case of highly curved ridges, the transformed coefficients are projected into widely curved sub-band of the DCT domain as shown in Fig. 20.

From Fig. 20, we can approximate the orientation range from θ_1 to θ_2 by a non-coherence factor from Eq. (2). The curved sub-band can be classified as one of two regions, either the principal region (R_1) or the reflection region (R_2). The principal region R_1 contains only one diagonal component (45° or 135°) as mentioned before. The 45° or 135° diagonal components correspond to the phase pattern of the oriented ridges in the range of 0° to 90° or 90° to 180°, respectively. The reflection region R_2 is composed of both 45° and 135° diagonal components from the reflection property of DCT coefficients. Then the convolution is applied only in the principal region.

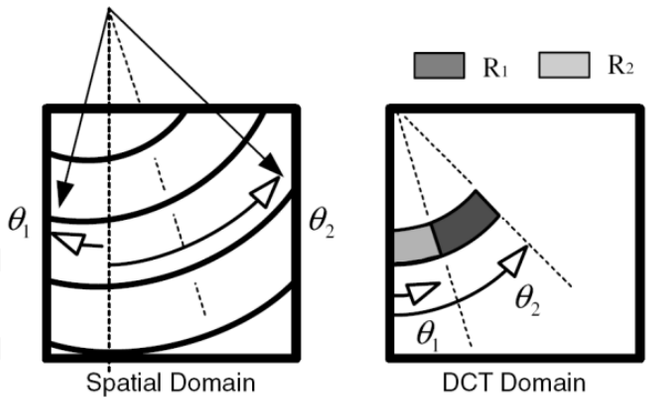

Figure 20. Highly curved ridges in spatial and frequency (DCT) domain. The signal is localized in a widely curved subband which can be classified as either the principal region (R_1) or the reflection region (R_2) [31].

It is then possible to compute a quality index of the fingerprint in the frequency domain [35] which gives us the information about the fingerprint image quality.

5. Fingerprint quality estimation

Quality of fingerprint image has a strong influence on biometric system performance. There exist several factors on which the final fingerprint quality depends: skin conditions, sensor quality and conditions, user cooperation and proper use of sensing device [36]. For the skin conditions the most influencing factors are dryness, presence of dirt and smudge and mainly the presence of skin disease. By the quality of the fingerprint image usually the ”clarity” of ridge and valley pattern is meant. Because of existence of different fingerprint quality measures and indexes the standardization of fingerprint image quality as a precisely defined unit was needed. Fingerprint image quality according the international standard ISO/IEC 19794-4:2005 is defined as an integer from interval <0, 100>, where 0 corresponds to the lowest possible fingerprint image quality and 100 corresponds to the best possible fingerprint image quality. Transformation of values from other quality indexes can be performed by, for example, normalization.

The process of fingerprint image quality estimation is very important part of fingerprint recognition system, because it enables for example:

- to reject fingerprints with very low quality during the enrolment process and force the user to perform a new attempt to enroll a quality fingerprint,
- to reject fingerprints with very low quality during the comparison process – for the non-forensic applications it is better way than false accept decision,
- appropriate choosing the comparing algorithm in systems having different algorithms for differently quality fingerprints,

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- to attach weights for each minutiae according the quality of fingerprint area in which they are located so during the minutiae based comparison process the weights of each minutiae are considered as well.

According to the source [28] the methods for fingerprint quality estimation can be divided into two categories: approaches based on local features extraction and approaches based on global features extraction.

Generally the process of fingerprint quality estimation consists of three phases:

1. Fingerprint area segmentation
2. Fingerprint foreground feature extraction (local or global)
3. Quality value estimation

Fingerprint area segmentation, sometimes also known as fingerprint foreground / background detection, is complex and difficult task.

5.1. Fingerprint area segmentation

The human finger and its fingerprint have a typical rounded shape. Fingerprint images from electronic dactyloscopic scanners are usually rectangles containing the rounded-shape fingerprint and of course a background. For the fingerprint processing purposes, mainly for the quality estimation process based on local feature extraction it is important to exclude the fingerprint background from the process. This needs to be done not only for speeding up the calculation time but also for making the estimation process more precise. Therefore, the main fingerprint foreground feature extraction is needed before the fingerprint area segmentation.

Generally the segmentation is a process of dividing the input image into several non-overlapping parts where usually the individual objects and the background are meant by the parts. If there is only one object in the image the segmentation can be called foreground/background detection. The fingerprint area segmentation is a process of detection which part of an image belongs to the fingerprint and which part of the image belongs to the background.

For our research we decided to test the following fingerprint area segmentation techniques: block grayscale variance method [37], *directional method* [37] and the *Gabor filter method* [38]. The block grayscale variance method computes variance of pixel intensity in each block and by using a set up threshold the decision logic marks each block as a background block or as a foreground (fingerprint) block. The block grayscale variance method is based on the idea that image blocks which contain fingerprint pattern have a high pixel intensity variance and the blocks with background have a low pixel intensity variance. The directional method described in [37] makes a foreground/background decision based on the block nominal direction computed from pixel nominal direction. This approach is based on the idea that the block with fingerprint has a high value of the block nominal direction and the others have a low value of the block nominal direction. The third method (Gabor filter method) [38] uses

eight different oriented Gabor filters for computing the vector of eight Gabor features. The standard deviation of these features can be used as a threshold for the foreground/background decision.

5.2. Local feature extraction based methods

Local feature extraction methods divide the input image into rectangular blocks of a specific size. Next step is to estimate fingerprint quality value for each block and by using these values to compute the fingerprint quality value for the whole image. The final fingerprint image quality value is usually computed as a rate of count of blocks with high fingerprint quality value divided by the count of all blocks. These blocks may also contain information about their weight. The weight of each block then corresponds to its quality.

In the presence we have the following implementations of the local feature based quality estimation algorithms: *directional contrast method, directional method, Gabor filter method and the check ratio method*. These methods work with blocks and compute a feature which characterizes the block and works as a quality index. The directional contrast method [39] computes the directional contrast of a local ridge flow orientation. The directional method uses the block nominal direction value and the Gabor filter method makes the quality value estimation by using the standard deviation of several different orientated Gabor filter responses. The check ratio method [40] is very simple and not precise method which presumes that the high quality fingerprints have a higher rate of foreground block count to the background block count. The success of the basic check ratio method mainly depends on the quality of the previous fingerprint image segmentation. However the check ratio method has a much better utilization because it can be used for weighting the result of previous three fingerprint quality estimation algorithms in order to make the quality estimation result more precise.

5.3. Methods on global feature extraction

The methods based on global feature extraction estimate the fingerprint quality value from the features extracted from the whole fingerprint image, not only some image block. The most important representative of this group is the method developed by the US National Institute of Standards and Technology (NIST) and its name is NFIQ *(NIST Fingerprint Image Quality)* rate. The NFIQ rate divides the fingerprint images into five categories according to their estimated quality. NFIQ defines the quality of an input image as a prediction of a comparison performance [28]. The fingerprints with a high quality will probably achieve a high comparison score. The NFIQ implementation uses a special vector of features for fingerprint quality estimation, created by the fingerprint quality map and statistics of its internal algorithm for minutiae extraction. These feature vectors are then used as an input for the multilayer perceptron neural network [41] which decides about the resulting fingerprint quality.

5.4. Creation of batch fingerprint quality estimation tool

One of the crucial tasks for the mapping the influence of dermatologic diseases on the fingerprint image quality was to design and implement an application for automatic batch fin-

http://dx.doi.org/10.5772/51992

gerprint image quality estimation. The main requirements were capability of batch fingerprint image batch processing using different processing algorithms and reusable extendable code design. During the design process the whole task was split into two important sub-tasks: the fingerprint quality estimation library and the batch processing tool graphical user interface.

The fingerprint quality estimation library was implemented in C++ programming language with the use of OpenCV 2.1 library for some image processing operation. The library provides three fingerprint segmentation algorithms (variance, directional and Gabor filter) and four fingerprint quality estimation algorithms (check ratio, directional contrast, directional and Gabor filter).

The graphical user interface was implemented in C++ programming language with the use of Qt 4.6 framework. The application observes the Model-View-Controller design model. The application uses the cooperating library algorithms for fingerprint segmentation and fingerprint quality estimation and due to fact that the check ratio quality estimation algorithm can be used as add-on for other quality estimation methods the application can batch process the all fingerprint images in specified directory by 21 different fingerprint quality estimation pipelines. Results of the fingerprint quality estimation are then normalized into 0 – 100 interval according the standard and can be exported into .csv or .xml file format.

5.5. Diseased fingerprints quality testing

The created database of fingerprints with a skin disease has been tested for the quality in the closest past. For the testing the implemented tool with all 21 local feature extraction based methods and the global NFIQ method were used. The results were normalized into interval from 0 to 100 where 100 means the best possible fingerprint quality. The example of obtained results of the most promising methods can be seen in Table 1.

Quality estimation method	*Cut wound*	*Verruca vulgaris*	*Atopic eczema*	*Psoriasis*
NFIQ	61	45	5	7
Variance method segmentation + Gabor filter quality estimation + Check ratio	48	53	41	37
Variance method segmentation + Directional quality estimation	10	11	10	13
Directional method segmentation + Directional contrast quality + Check ratio	48	52	51	48

Table 1. Example of results of diseased fingerprint quality testing.

6. Conclusion and future challenges

The dermatologic diseases have a strong negative influence on the process of fingerprint recognition and are causing problems to people who are suffering from them. These people are discriminated because they cannot use the fingerprint recognition systems which are very common these days. Currently there exists no usable database of fingerprints affected by a skin disease. As a first step in this wide and complex research we designed and developed a special diseased fingerprints capturing station. With this station the medical experts captured the first version of this special fingerprint database. A special algorithm for fingerprint image enhancement has been designed and fingerprint batch processing tool has been implemented. The first diseased fingerprint quality testing has been realized. Our greatest challenge in the nearest future is to develop an algorithm for distinguishing diseased fingerprints from the other fingerprints with a low quality.

In the nearest future the several challenges will be needed to face. First,the global analysis of the results of testing of the quality estimation algorithms has to be done. We will try to find out why some quality estimation algorithm failed and why some did not fail. The biggest challenge for us will now be to design and implement an algorithm for dermatologic disease presence detection. This algorithm should be able to detect whether the fingerprint with a low quality is diseased or if it is not and the low quality is caused for example by dirt, dry skin, mud etc.

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