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**METHOD FOR DETERMINATION OF AN IDENTIFICATION CODE
FROM FINGERPRINTS**

The invention concerns a method and a device for determination of identification codes from fingerprints or from digital gray scale value images respectively according to the generic terms of claims 1 and 25. These are for the automatic identification of fingerprints of a person in real time or from an image document by means of an electronic image recording device, e.g. a video camera. With this a code can be generated from fingerprint images in digital form with which code the appertaining persons can be identified. Mostly the finger is pressed onto a suitable optical device for creating contrast which device generates an image of the skin lines by means of prisms and the principle of impeded total reflection. Skin line images can, however, also be directly recorded electronically, e.g. capacitively. Up to now for characterization of a fingerprint minutiae of all kinds (bifurcations, ridge ends, inclusions, islands, interruptions, junctions, trifurcations etc.) have been used. This is especially valid for the widely used forensic applications which require a very accurate analysis of these minutiae characteristics (position and kind of minutiae as well as their orientation) which again require a correspondingly large amount of memory and complicated programs.

Furthermore the characterization by means of known minutiae methods further has a series of additional drawbacks: on the one hand errors and inaccuracies of the optical

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image recording can lead to confusion of the minutiae, i.e. an error of the image recording generates apparent minutiae which do not really exist and on the other hand existing minutiae cannot be recognized due to poor image recording. Additionally the actual finger line image of a person can contain minutiae errors, e.g. due to injury of the skin, by pollution or poor recordability of the skin lines such that e.g. interruptions appear in the image. Due to e.g. a simple injury in form of a cut a large different set of minutiae, i.e. apparent ridge ends can be formed along the edge of the cut. Thus the recorded minutiae image of a person is not always identical, which again requires complicated evaluation programs. For these reasons the determination of fingerprints by means of known minutiae methods requires much effort concerning calculation and memory.

Other known methods for determination of identification codes from distances between ridges or from gradients have not yet been capable of a sufficient security of recognition with short codes.

On the other hand there is considerable demand for the identification and verification of persons with simple means for use in a large number of applications for everyday use., e.g. selective access, for payment by means of credit cards, for identification for legal or social purposes, e.g. passport control or for inspection of personal documents, e.g. for social programs etc. For all these non-forensic applications it would be necessary to find a more simple and more secure biometric identification code which requires very little memory and thus can also be used for inexpensive data carriers. Especially for inexpensive magnetic cards, for documents with one- or two-dimensional bar-codes or on other inexpensive data carriers, especially also for chips with EEPROM memories of smart cards and contactless data carrier systems. This is also absolutely necessary for all applications which concern the handling of business dealing with relatively low sums of money, e.g. in the field of everyday consumer goods, with vending machines with a relatively large amount of users. For this kind of applications the identification carrier must be very inexpensive, i.e. must

be applicable securely with small capacity of memory and relatively simple evaluation in small local computers of testing stations.

The object of the present invention is thus, to create a method with a better ratio of necessary code length and computing effort to the precision of determination and
5 especially to generate a shorter and simpler code at a sufficiently high precision of determination which code can consist of less than 100 byte, e.g. only 36 byte or even less. The code is also to be less sensitive concerning image errors and recording errors as well as concerning the choice of the image section. Furthermore the generation of this code is also to be possible in local stations with simple,
10 inexpensive computers.

This object is inventively achieved by means of a method according to claim 1 and a device according to claim 25.

By using at least two of the independent or orthogonal features ridge distance L, gradient G, curvature C and bifurcation B a multiplication of the determination
15 precision of the two features is substantially achieved and with the determination of compressed characteristic values from the frequency distributions of the features, code features are determined in a simple manner which is additionally less dependent on recording and image errors. With the inventive method it is also possible to achieve higher determination precision basing on few characteristic values or very
20 short identification codes for simple applications respectively can be achieved if required by increasing the number of features or the code length. Advantageous further developments of the invention are stated in the dependent claims.

In the following description of the different method steps as well as in connection
25 with figures and examples the invention is described further, whereby:

Fig. 1 shows a determination of the ridge distances L in x-direction

Fig. 2 shows a determination of ridge distances from gray scale value images

5 Fig. 3 shows a determination of L in x- and y- direction

Fig. 4 shows frequency distributions HL as a function of distance length L

10 Fig. 5 shows a classification with determination of class values

Fig. 6 shows a determination of gradients G

Fig. 7 shows a determination of curvatures K

15 Fig. 8 shows a representation of class values of gradient distributions HG of different images.

Figs. 9 to 11 show different fingerprint images I

20 Fig. 12 shows a determination of bifurcations B in a skeletated image

Fig. 13 shows a determination of bifurcation distances LB

25 Fig. 14 shows a determination of bifurcation areas F

Fig. 15 shows a further example of a determination of bifurcations B

Fig. 16 shows a segmentation and the covering of an image with a grid

Fig. 17 shows representation of possible image sections

Fig. 18 shows a diagrammatic representation of the inventive method

5 Fig. 19a, b show examples of defined bifurcations

Fig. 20 shows an inventive device for carrying out the method

Fig. 21 shows an illustration concerning the classification of bifurcations.

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For image determination a digital gray scale value image of a fingerprint with a suitable grid of e.g. 512 x 512 pixel is recorded by means of known methods (Figs. 9 to 11). This digital image can either be used directly for determination of the characteristics or a finger line image can be created from it by means of image pre-processing, especially by means of binarization and of skeletation (Figs. 12 and 15). Different characteristics are then drawn from this once created image and are compressed into an identification code C in further processing steps which code corresponds to the desired application concerning its length and determination precision.

20

Fingerprint features

25 The following four substantially independent or respectively orthogonal features (characteristics) are used and their frequency distributions are determined:

L Ridge distances

G Gradients

K. Curvatures

B. Bifurcations

5 Feature ridge distances L

The ridge distances (distance lengths) L are, as illustrated in Figs. 1 and 2, defined as distances between two succeeding finger lines (ridges) 5, whereby the finger line has a width 0, i.e. corresponding to the distances between the middles of two successive
10 finger lines which are recorded in the direction of a projecting ray X. For pre-processed, skeletated images this corresponds to a ridge distance (with ridge width 0, Fig. 1), while with digital gray scale value images according to Fig. 2 between two successive finger lines, the distance L is to be calculated as follows:

$L = L_2 + \frac{1}{2} \times (L_1 + L_3)$. If L1 and L3 correspond to the finger line widths with a
15 suitably chosen gray scale threshold value 10. With this threshold value 10 a binarization can also be carried out, by terming gray scale values De above the threshold value as 1 and gray scale values below the threshold value as 0. For elimination of errors of individual pixels it can be predetermined as a condition that the ridge widths L1, L3 and also the distance L2 must e.g. amount to three successive
20 pixels. The determination of the occurring distances Lx1, Lx2 etc. in direction of a recording ray, e.g. the abscissa x is carried out as shown in Fig. 1. The complete image is then recorded by variation of y in suitable steps dy according to Fig. 3, such that the quantity of all recorded occurring distances HLx (x, y) can be plotted as a function of the distance lengths Lx according to Fig. 4. This shows the frequency
25 distribution or histogram of all occurring distances Lx in x-direction over the recorded image region.

In analogy to this the distances Ly (x, y) are determined in orthogonal direction (i.e. in the direction of ordinate y) and recorded over the whole image region by means of

variation of x with the chosen distances dx . This leads to a histogram HL_y , again over the whole image region.

For determination of the distance lengths L_x and L_y in x -direction and in y -direction the grid must be orientated in a defined manner: here with the y -axis corresponding to the longitudinal axis of the finger in order to achieve defined histograms. The histograms HL_x and HL_y are completely different as seen in Fig. 4.

Fig. 5 shows a classification of a histogram HL_x , whereby for each class $H_c = 1, 2, 3, \dots$, e.g. the mean values H_q , maximum values H_{max} and standard deviations or variance H_{var} are determined and used as characteristic values C_i of identification code C . Histograms HL_x and HL_y can e.g. each be classified in 8, 12 or 16 classes and then one, two or three values (H_q , H_{max} , H_{var}) can be determined for each class.

Feature gradients G

In analogy to the feature distance lengths the histogram of the gradients G , i.e. of the first direction derivations is also registered regularly over the whole image region and for this purpose again recorded e.g. per projection direction. The gradients are determined as tangent to skin line 5 in the point of intersection of the projection ray (e.g. in x -direction) with the skin line. As shown in Fig. 6 the gradients are registered via the projection direction and its histogram HG_x is recorded for projection direction x over the whole image region and in analogy to this the histogram HG_y of the gradients in projection direction y , in order to regularly record the gradient directions $G(x, y)$ over the whole image region.

This histogram of G can also be recorded in an image covering manner by determination of a gradient value for each mesh of a grid (30, Fig. 16) in order to register a gradient grid. This is explained in more detail further below.

5 As illustrating example the histograms HG of the gradients for the three fingerprint images of Figs. 9, 10 and 11 were determined and are shown in Fig. 8. The image I1 of Fig. 9 shows the fingerprint of a person 1 and the images I2a and I2b show fingerprints of a second person, whereby Fig. 10 shows fingerprint I2a without errors and Fig. 11 shows the same finger of the same person in image I2b with errors or
10 injuries 20 respectively. The histograms HG of these images were recorded over the whole image and are shown as a function of the gradient angle of 0 to 180°. Basing on this a classification into 16 classes, i.e. each class with $180^\circ : 16 = 11.25^\circ$ angle region, was carried out and the mean values Hq of each class were determined and are shown in Fig. 8. The results is a graph with 16 feature values for each image. As
15 can be seen clearly the graphs of these images I2a and I2b according to Figures 9 and 10 are nearly identical; i.e. with a correspondingly defined threshold value S both images are classified as identical. Thus the identification of this person 2 is still possible although the images I2a and I2b differ, firstly due to the errors 20 from injury, secondly due to not identically recorded image regions. As shown in Fig. 11, the recorded image region I2a on its edges does not correspond to the image region I2b (differing definition of image region).

In the case of a known minutiae evaluation many new pseudo-minutiae (ridge ends) would occur in image I2b in the injured areas 20 and thus identification would be
25 connected with much effort or even be impossible respectively. The graph of image I1 of person 1 of Fig. 9 visibly differs considerably from graphs I2a and I2b of person 2. Thus the 16 feature values Ci provide a relatively good contribution to the security of recognition of the identification code C as partial code C1 of feature G. This example also illustrates that the inventive determination of histograms of the

named features over a large image region and from this the determination of compressed feature values amounts to an identification code which is only affected by local image errors to a relatively small degree such that correspondingly a relatively increased security of recognition is achieved. This is in contrast to known
5 minutiae evaluation.

As previously explained in connection with the determination of distances L the features gradients G can also be determined directly from digital gray scale value images, e.g. by means of determination of a gradient value for each mesh of a grid 30
10 and thus of a gradient grid which is explained in connection with Fig. 16.

Feature curvatures K

15 The curvatures K according to Fig. 7 are determined in the intersection points of the skin lines or finger lines 5 with the projection directions x and y as second direction derivations of the finger lines. This is e.g. determined as inverse radius R of the approximation circle to finger line 5 in the concerned intersection point. In analogue manner to the feature determination described so far, here the histograms of the
20 curvatures are again determined over the whole image region in the two orthogonal directions x and y, i.e. HKx and HKy (or by determination of the K-value for each mesh 30). In order to exclude irrelevant very small curvature radii which can be formed due to irregularities of a skeletonized image choice rules can be applied, e.g. $R_{min} = 0.3 - 0.5$ mm such that the narrowest curvature radius in the center of the
25 image is included, but not, however, even narrower curvatures, e.g. at the bifurcation B5.

As explained previously in connection with the determination of distances L the feature gradients G and possibly also the curvatures K can also be derived from digital gray scale value images or from binarized but not yet skeletonized images.

- 5 Inventively only the independent features ridge distances L, gradients G and bifurcations B (skin line bifurcations) are used of which at least two of these features must be used for code determination.

10 The features L, G, K are not minutiae features; they are characterized by their histograms. The special feature bifurcations B is also chosen and included in a manner that image errors, e.g. the absence of one single bifurcation e.g. in the margin – which can be recorded once and not recorded another time – have no or no substantial effect.

- 15 It is important that the sought after short identification code C is as independent of individual image errors or of one single feature (e.g. of differing individual minutiae) as possible. For this reason the sole minutiae characteristic which is used as feature can only be clearly defined bifurcations B, whereby these bifurcations B, in contrast to other minutiae, are relatively insensitive to image errors or to apparent mistakes due to disturbances of the finger lines e.g. due to injury from cutting. Injuries due to cutting can create new ridge ends as apparent minutiae, but not, however bifurcations.
- 20

- 25 It is important that the clearly defined feature bifurcations B applied here is used in a different manner than in the conventional evaluation of minutiae. The conventional evaluation registers different kinds of minutiae and of each minutia its position, its kind and its orientation, whereby for evaluation and code determination the relative positions of these different individual minutiae are brought in. Inventively, however, only one kind of minutiae is chosen, clearly defined bifurcations, which are

additionally used in completely different manner than up to now. This is explained in what follows: as histogram or as individually skeletonized bifurcations.

5 Feature bifurcations B

Fig. 12 shows a binarized and skeletonized representation of the gray scale value image of Fig. 10 which is used as an example for the determination of bifurcations. In this image the bifurcations $B_i = B_1 - B_{12}$ are determined, this results in an quantity of N
10 = 12 bifurcations B. For this purpose suited choice rules or definition criteria respectively are set up, such that small errors and other kinds of minutiae (e.g. islands) are not counted as bifurcations. The rules are e.g.: a registered bifurcation must have a minimum length of 0,5 – 1 mm of all three branches and one branch must have a length of at least 1 – 1.5 mm. Furthermore a minimum distance between
15 two bifurcations of e.g. 0.7 – 1 mm can be prescribed. According to such definition criteria e.g. (B13), (B14) in Fig. 12 and (B7), (B8), (B9) in Fig. 15 are not counted as bifurcations.

Bifurcations B can be used as defined individual or selected bifurcations for
20 generating a code, as is explained in connection with Figs. 19 and 21, or, according to Figs. 13, 14 histograms e.g. of bifurcation distances as well as of adjacent triangular areas F between the bifurcations can be determined.

According to Fig. 13 the bifurcation distances LB are determined as follows:

25 The distance LB_{i-j} between the N bifurcations B_i and every other bifurcation B_j are determined. This results in $N(N-1)$ bifurcation distances LB_{i-j} . In the example with $N = 12$ this results in 132 distances which are drawn up in a histogram: as frequency distribution HLB in function of distance LB.

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In analogy to this, triangular areas F_{i-j} between bifurcations B_i and B_j are determined according to Fig. 14. A first side of triangle is defined, which reaches from each bifurcation B_i to each other bifurcation B_j , whereby the third point of the triangle is determined to be the bifurcation B_k (with $k \neq j$) closest to bifurcation B_i ; e.g. starting from B_1 , the area F_{1-2-3} (with $i = 1, j = 2, k = 3$) and F_{1-3-2} (with $i = 1, j = 3, k = 2$) as well as F_{1-4-2} until F_{1-12-2} . With this choice rule it is guaranteed that only one area is registered per bifurcation, e.g. in the case that two closest bifurcations are B_k -bifurcations only the one closest to B_j is used as B_k . Starting from B_{10} to B_1 the area $F_{10-1-12}$ ($i = 10, j = 1, k = 12$), i.e. starting with each B_j as a base line, this results in exactly one triangle, thus again a sum of $N(N-1) = 132$ areas F_{i-j} , which again form a histogram with frequency distribution as a function of area F .

Fig. 15 shows a further example for determination of bifurcations from another fingerprint image, whereby by means of corresponding choice rules, e.g. that the very closely situated bifurcations B_7, B_8, B_9 are not counted as bifurcations for evaluation, such that here this leaves only the bifurcations B_1 to B_6 and thus the quantity of bifurcation distances LB as well as that of the closest triangular areas F is each $N(N-1) = 30$. With other definition criteria, e.g. only B_9 could be defined as bifurcation but not B_7 and B_8 .

Determination of feature values

From the histograms simple feature values C_i which characterize the histogram are determined, e.g. mean values H_q , maximum values H_{max} and variances H_{var} .

Furthermore a histogram can also be classified into classes H_c and e.g. mean value and variance can be determined as characteristic values (Fig. 5).

Selected bifurcation features

The feature bifurcations can additionally be used in a non-statistical manner by using individual clearly defined bifurcations with determined bifurcation features for determination of code features C_i and identification code C . Hereby the bifurcations are, as illustrated in the examples of Fig. 19a and 19b, determined via their position, i.e. the local coordinates x_1, y_1 of point P_1 are determined as well as the orientation angle W_a and the opening angle W_b . A clearly defined opening angle W_b can e.g. be defined as the angle between the connecting line of points the P_1, P_2 and P_1, P_3 , whereby points P_2 and P_3 are chosen at a suited distance r_1 to point P_1 , e.g. $r_1 = 0.5 - 1$ mm. A point P_4 with a minimal distance r_2 of e.g. 1 to 1.5 mm from point P_1 on the other hand form a definition criterion for a bifurcation, so that small image errors are not wrongly counted as bifurcations. In the example of Fig. 19a a relatively small bifurcation angle W_b is shown, e.g. corresponding to bifurcation B_6 in Fig. 2, while the example of Fig. 19b shows a large opening angle W_b , e.g. similar to the one in bifurcation B_8 in Fig 21. Identified bifurcations can now be classified for code-determination, i.e. sorting criteria such as e.g. a valence for the bifurcations is introduced. A first classification criterion is the opening angle W_b , whereby large opening angles have higher valences. The classification criterion can e.g. be: a valence in proportion to opening angle W_b . A further sorting criterion is the distance RB_i of the bifurcation to a central reference point, here e.g. the distance RB_i to the curvature center K_m (Fig. 21), whereby the central bifurcations have higher valences than those further away. As a further criterion of selection, bifurcations which are close to the margin, e.g. B_2 in Fig. 21 which are near the outer contour A of the finger line image can be left away. From the bifurcation features and the classification criteria e.g. a bifurcation priority can be defined as $BP = W_b/RB$. With this all bifurcations can be sorted in descending order according to BP . For generating a short code length the first entries of the list sorted according to

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bifurcation priority can be used. A possible order for Fig. 21 can e.g. be the following: B8, B6, B5, B7, B4.

By means of combination of the feature gradients and bifurcations especially concentrated codes with relatively high security of recognition can be created. An
5 identification code C which on the one hand consists of gradient features for each segment IS of a gradient grid and on the other hand of classified bifurcations B is particularly advantageous. For this purpose a central reference point and the orientation of the finger line image are required.

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Image-preprocessing

The features L and G can be determined directly from the digital gray scale value image without further image pre-processing.

15 The determination of features B and also of K is mostly carried out by means of a line thinning as image pre-processing, e.g. a binarization and skeletonation. Then the other features L, G, K are determined from the skeletonated image.

In an advantageous variant the bifurcations B can, however, also be determined directly from the digital gray scale value image by means of neuronal grids.

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The features can be registered in following manners, as is illustrated in Fig. 16 with segmentation and mesh classification:

a in the whole image region (also for features L, G, K, B)

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b in each of a few relatively large segments, e.g. divided in 3 x 5 to 5 x 7 segments IS, whereby histograms are determined for each segment IS and feature values are derived from them.

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- c covering of an image I with a grid 30, whereby for each mesh only one value of the feature is determined. The size of the mesh is chosen suitably. (e.g. 5 x5 pixel)

- 5 With these kinds of registration a, b, c the following features are registered:

	<u>a</u>	<u>b</u>	<u>c</u>
	Features		
	L	-	-
10	G	G	G
	K	K	K
	B	-	(B)

- 15 When comparing the codes it must be paid attention to that the division into segments IS is dependent of translation and rotation of the recorded images. For comparison of codes this must be taken into consideration.

- 20 The feature curvatures K is independent of rotation; the same is valid for the bifurcation lengths BL and bifurcation areas F derived from bifurcations B and the relative positions of selected bifurcations. The feature gradients G requires a determination of the image-orientation-axis y. The feature gradients G, on the other hand, is independent of image dilatations (magnification and diminution of the image).

- 25 Because at least two features (L, G, K, B) are contained in the identification code C = (C1, C2) as partial codes (C1, C2) these partial codes can also be used correspondingly differently for the code evaluation, i.e. corresponding to the dependence on the image definition and to the dependencies of the concerned feature and the histogram evaluation or the selected bifurcation features respectively.

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Partial codes can be formed at choice from any feature values C_i .

Image section

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Fig. 17 illustrates the dependence of the image definition, whereby two images were recorded of the same finger, first an image I3 and then an image I4, whereby these images I3, I4 show different regions and possibly also different orientations of longitudinal axis y of the fingerprint. In order to always be able to compare similar image regions it is also possible to cut a central portion out of a given fingerprint image which portion can then be used as image section IA for determination of features and generating a code. Hereby regions from center Z of a fingerprint and its surroundings ZU are advantageously used for registration of features and code generation because the information content is higher here than in the marginal regions.

15

With a well defined position and orientation of the images, by means of corresponding image recording devices, e.g. a guidance for two fingers, segmented images can also be compared at higher security.

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Orientation and central reference point

For determination of the orientation and a central reference point of a finger line image or for the definition of a grid with an origin of coordinates e.g. a so called core point can be defined in known manner. This, however, is connected with large effort and often no clear core point can be determined. A simpler method consists in determining a curvature radius gravity center K_m as central reference point from the feature curvature K. For this purpose the centers of the approximation circles (see R

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in Fig. 7) to the curvatures are determined and of these regularly recorded circle centers of the approximation circles the gravity centers K_m with coordinates x_m , y_m are determined. A central reference point can, however, also first be determined by approximation e.g. as gravity center of the image area with outer contour A (in Fig. 5 21). Similarly the recording of a finger image recorded in a defined manner by means of guiding means 32, as described in connection with Fig. 20 can be used. A further possibility is to determine a central reference point from the variance H_{var} of the gradient distribution in image segments IS , whereby the central reference point is determined by the segment which has a maximum of variance. For this purpose the 10 image segmentation can also be varied.

With a poorly defined position of an image to be recorded, the features, manners of determination and code determination must be chosen such that they are relatively independent of position, e.g. the features G , K according to determination manner a, 15 whereby, however, in most cases the direction should be determined for support. For code comparison the image can also be rotated over a small angle region or shifted in x - and y -direction.

As realization variants of the inventive method, depending on image definition and 20 the objective to be achieved, e.g. the following combinations of the features for determination of an identification code C can be used:

1. features ridge distances L , gradients G and bifurcations G .
These can e.g. also be determined from gray scale value images and be used 25 especially for simpler, shorter codes (L and G), e.g. also with a classification of histograms.

From skeletated images the following features can be used:

2. the features gradients G and curvatures K
3. the features gradients G and bifurcations B
4. the features curvatures K and bifurcations B, which are both invariant to rotation.
- 5 5. the features gradients G, curvatures K and bifurcations B, this specially for higher precision, whereby corresponding to the higher precision longer codes are formed (also with selected bifurcations).

- After suitable choice of the combined features the precision, with which the features and their histograms are determined as well as the determination of the feature values C_i from it, can be chosen such that finally an identification code C with a code length with the desired demands to precision is formed, i.e. the code length can be enlarged as far as demanded, by narrower segmentation and classification and by determination of more feature values C_i .
- 15 The identification code C cannot only be determined sequentially but also in iterative manner.

Code comparison

- 20 With these inventive, relatively compact identification codes C (with minor demand of memory) all in fact known identification, verification and authentication tasks can also be carried out in local, simple and rational manner. Hereby, for the comparison of two codes C_a and C_b , e.g. a code of a recent fingerprint image C_a with a reference code C_b from an allocated memory (which can be a databank or also an identification medium IM) is determined by means of mathematical methods a code difference $D = C_a - C_b$ and is compared to a pre-determinable threshold value (an acceptance value) S. In the case that $D < S$ the two codes C_a and C_b and therefore the appertaining persons, are found to be identical.
- 25

Hereby individual threshold values specific to persons can be given. E.g. dependent on how well the identification code C of a certain person is to be determined and on the other hand also on how important this identification task for this person is.

- In similar manner a threshold value S can be predetermined, corresponding to the
 5 concerned application, i.e. which security of recognition is desired, i.e. which FAR false acceptance rate and which FFR false rejection rate is permissible.

- For determination of this correspondence e.g. the euclidian distance D of the feature
 vectors C with a predetermined correspondence threshold S can be determined. This
 10 means for a code, formed from the feature values C_i , that a fingerprint 1 is identical to a fingerprint 2 when:

$$D = \sum (C_{1i} - C_{2i})^2 < S$$

- 15 As an alternative the identification codes can also be correlated according to the following method:

A correlation Kor between the features of a finger a_i with $i = 1, N$ and a second finger b_i with $i = 1, N$ according to the formula:

20 $-1 \leq Kor = \sum (a_i - a_q) (b_i - b_q) / (\sum (a_i - a_q)^2)^{1/2} \leq +1$ for $i = 1, N$

is formed, whereby a_q is the mean value of the values a_i and b_q is the mean value of the values b_i .

- For $a_i = b_i$ the fingers are identical, i.e. the correlation is 1. At $Kor = 0$ the features
 25 are not correlated, at $Kor = -1$ they are anti-correlated.

Further possible methods of comparison are, depending on the type of code C regression analysis or moment analysis. Furthermore the different features or feature

values C_i respectively and corresponding partial codes C_1 , C_2 of an identification code $C = (C_1, C_2)$ can also be treated differently.

Fig. 18 diagrammatically illustrates the inventive method for determination of a relatively short identification code C . The choice 52 of at least two of the orthogonal features L , G , K , B as well as the choice of the following method steps on the one hand bases on the image definition 51 and on the other hand on the task 60, i.e. on the required security of recognition of the desired applications, from this the required false acceptance rate FAR and the required false rejection rate FRR. Depending on the image definition 51 (i.e. quality of orientation, section, image recording and image quality) correspondingly less sensitive features and kinds of registration are chosen. Likewise a possible image pre-processing 53 can be carried out for a direct feature determination from the gray scale image, from a binarized image or from a thinned, skeletated line image. In a next step 54 a possible image orientation, a central reference point or an origin of coordinates, e.g. K_m , as well as the choice of an image section IA or a segmentation IS respectively can follow. From this, histograms H with correspondingly fine screening or quantity of data respectively are determined. In addition to the histograms individual defined features bifurcations B with position, orientation angles W_a and opening angles W_b can be determined in step 56 and in step 57 a classification of bifurcations, a skeletation or valences according to a bifurcation priority BP respectively can be carried out. In step 58 the determination of the feature values C_i is carried out and in step 59 the composition of the identification code C is carried out. I.e. a corresponding longer or shorter code length is composed until the desired security of recognition FAR and FFR according to step 60 is achieved. Corresponding to the composition of code C the methods of evaluation and the threshold values S for the identification evaluation can be chosen. The identification evaluation (comparison) $C_a - C_b = D < S$ is carried out in step 62. Thus the inventive method is universally applicable for a wide range of applications

and is also optimally matchable to the desired tasks concerning computing effort and length of code.

5 Fig. 20 shows a device for carrying out the method with an electronic image recording device 31 and a station with evaluation electronics 34 and with evaluation
logarithms 35 for determination of feature values C_i and from these of the
identification code C or C_a respectively, i.e. of the actual identification code
corresponding to the image recording of fingers 1, 2 to be recorded and for carrying
10 out a comparison of codes $C_a - C_b$ between a saved reference code C_b and the actual
code C_a . This code comparison can also be carried out in a corresponding reading
station WR . Corresponding to the code comparison, i.e. to the verification of the
actual person, access functions for control of corresponding function stations can be
practiced. The image recording device 31 here comprises guiding and positioning
15 means 32 with limit stops for orientation and positioning of one or of two adjacent
fingers 1, 2 to be recorded. Additionally a lateral limit stop for positioning of the
longitudinal axis of the finger and a front limit stop for positioning of the finger
image and thus for determination of a central reference point or a center of the finger
image respectively can be provided. This kind of two-finger-recording device is e.g.
20 disclosed in PCT CH97/00241 = WO 98/09246. With an inventive device a code
comparison $C_a - C_b$ can be carried out locally such that no central databank with
reference codes C_b are required. The inventive device can also comprise
corresponding identification media IM for authorized persons, whereby the reference
code C_b of the person and further information is contained in the identification
25 medium IM or in its memory 43 and whereby an encoded communication 40 with an
corresponding reading station WR can be carried out. Hereby the reference code C_b
of the authorized person is only stored on the identification medium and not in the
verification station or in a databank respectively. This makes a better data protection
possible.

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In a further variant a code comparison $C_a - C_b$, i.e. of the actual code C_a with the reference code C_b of the person, by means of processor 41 can also be carried out in the identification medium itself. In this case the actual code C_a must merely be transmitted from the reading station WR to the identification medium, while no code
5 must be transmitted from the identification medium. In another variant the device can also be connected with a master system 47 with a main processor and with a databank 48 for reference codes C_b . The identification medium IM can contain access and function authorizations for further corresponding function stations 46 of a facility.

10

Pre-selected databank search

In applications in which a fast databank search is required for positive identification
15 of individual persons from an inhabitant databank with a large quantity of reference codes C_b solely by means of biometric recognition features the identification can be carried out in steps. Hereby the comparison is not carried out with the complete biometric identification code C_a but only with partial codes or with individual feature values C_i respectively such that the search can be carried out considerably
20 faster. In a first step e.g. only a partial code C_1 is compared and the remaining reduced quantity is then compared to a second partial code C_2 in a second step etc. This continues up to the complete code evaluation with a very small remaining quantity from the databank. This kind of search is considerably more rapid than a search for the complete identification code C . Advantageously the search for primary
25 biometric data is classified, i.e. e.g. gradients and selected bifurcation features are used in steps for this purpose. A further method consists in the forming of gradient segments according to the method of quadrant segmentation (quad trees). Hereby the image is divided into four segments from each of which a gradient histogram is formed. In the next step each quadrant is again divided into four quadrants etc. until

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finally the gradient histogram would converge to the main line tangent in the considered segment.

The following terms are used in the description and in the figures:

- 5 L ridge distance
- G gradients
- K curvatures
- B bifurcations
- LB bifurcation distances
- 10 F bifurcation areas
- H frequency distributions, histograms $H(L)$, $H(G)$, $H(K)$, $H(B: LB, F)$
- Hc classification of H
- Hq mean values
- Hmax maximum values
- 15 Hvar variance of H
- De gray scale value
- I1, I2 fingerprint images
- IA image sections
- IS image segments
- 20 C identification code (feature vector C_i)
- Ca actual code
- Cb reference code
- C1, C2 partial codes
- Ci feature values
- 25 D code difference
- S threshold value, acceptance value
- Z center
- ZU surrounding
- x abscissa

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- y ordinate, longitudinal axis of finger
- dx, dy screening
- FAR false acceptance rate
- FRR false rejection rate
- 5 IM identification medium, data carrier
- WR reading station
- BP bifurcation priority
- P1 – P4 definition of Wb
- r1, r2 distances
- 10 Wa orientation angle
- Wb opening angle of B
- P1(x1, y1) local coordinates of B
- Km curvature radius gravity center
- xm, ym coordinates of Km
- 15 RBi distance from central reference point to Bi
- A outer contour of finger image I
- 1, 2 finger
- 5 finger lines, skin lines
- 20 10 gray scale value
- 20 image error, injury
- 30 grid
- 31 image recording device
- 32 guiding and positioning means
- 25 34 evaluation electronics, evaluation station
- 35 evaluation algorithms
- 40 encoded communication
- 42 processor
- 43 memory

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	46	access function (function stations)
	47	master system, main processor
	48	data bank
	51	image definition
5	52	choice of feature L, G, K, B
	53	image pre-processing, skeletation
	54	image section, segmentation
	55	forming histograms
	56	determining bifurcations
10	57	classification, choice of B
	58	determining feature values C_i
	59	determining identification code C
	60	applications, demands (FAR, FRR)
	61	evaluation method, choice of threshold value S
15	62	identification comparison C_a - C_b

CLAIMS



1. Method for determination of an identification code from fingerprint images or from digital gray scale value images, characterized in that at least two of the following independent features: ridge distances L, gradients G, bifurcations B are registered and that from at least one of the features histograms H are determined from which characteristic values (mean value, variance, maximum) are determined as compressed feature values C_i which as vector components form the identification code C.
2. Method according to claim 1, characterized in that the features gradients G are used.
3. Method according to claim 1 or 2, characterized in that the histograms H are determined in at least two orthogonal directions (x, y).
4. Method according to one of the preceding claims, characterized in that an image pre-processing is carried out, e.g. by means of binarization and skeletonation.
5. Method according to one of the preceding claims, characterized in that a classification H_c of a histogram is carried out, whereby at least one characteristic value for each class is determined as a feature value C_i .

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6. Method according to one of the preceding claims, characterized in that the recording image I is subdivided into several segments IS and that the histograms H of features (L, G, K, B) are determined for each segment IS.
- 5 7. Method according to one of the preceding claims, characterized in that the identification code C is derived from an image section IA which comprises the center Z of the fingerprint image and its surrounding ZU.
8. Method according to one of the preceding claims, characterized in that the length of the identification code C is chosen such that the demand for precision or the recognition security respectively (FAR, FRR) are fulfilled for a desired application.
10
9. Method according to one of the preceding claims, characterized in that partial codes C1, C2 of the features are determined differently and/or used differently for the code evaluation.
10. Method according to one of the preceding claims, characterized in that defined individual bifurcations B are used as features.
15
11. Method according to claim 10, characterized in that the features bifurcations B are determined directly from the digital gray scale image by means of neuronal grids.



12. Method according to claim 10, characterized in that the features bifurcations B are classified according to their opening angle W_b and/or according to their position in the fingerprint.
- 5 13. Method according to claim 10, characterized in that for classification a bifurcation priority BP is defined, whereby the bifurcation priority increases as the opening angle W_b increases and the distance R_{Bi} to the image center decreases.
14. Method according to claim 10, characterized in that the bifurcation priority BP is defined as $BP = W_b/R_{Bi}$.
- 10 15. Method according to one of the preceding claims, characterized in that a central reference point is defined as origin of coordinates of the fingerprint image.
16. Method according to claim 15, characterized in that a curvature radius gravity center K_m is defined as a central reference point.
- 15 17. Method according to claim 15, characterized in that the variance H_{var} of the gradient distribution in image segments IS is determined and the central reference point is determined by the segment which has a maximum variance.
18. Method according to one of the preceding claims, characterized in that by means of guiding and positioning means (32) the longitudinal axis (y) of the

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finger and a central reference point are determined at least approximately when recording the image.

19. Method according to one of the preceding claims, characterized in that the features gradients G and bifurcations B are used.
- 5 20. Method according to claim 19, characterized in that the identification code C is formed from gradient characteristics for each segment IS of a gradient grid and of classified bifurcations B.
- 10 21. Method according to one of the preceding claims, characterized in that partial codes are formed and that a comparison $C_a - C_b$ with a large quantity of reference codes C_b of a data bank (48) is carried out in steps corresponding to the partial codes.
22. Method according to claim 21, characterized in that the evaluation in steps is carried out by means of gradient segments and the method of quadrant-sub-division (quad trees).
- 15 23. Method according to one of the preceding claims, characterized in that an actual identification code C_a is recorded and determined and compared locally by means of an corresponding reading station WR to a personal reference code C_b stored in a corresponding identification medium IM.



24. Method according to one of the preceding claims, characterized in that the identification code C is determined in a sequential and/or iterative manner.
25. Device for carrying out the method according to one of the preceding claims, characterized by an electronic image recording device (31), a station with evaluation electronics (34) and with evaluation algorithms (35) for determination of an identification code C, Ca and for carrying out a code comparison $Ca - Cb$ with a stored reference code Cb as well as with an access function (46) for the control of corresponding function stations.
26. Device according to claim 25, characterized by guiding and positioning means (32) with a lateral and a front limit stop for orientation and positioning of one or two adjacent fingers (1, 2) to be recorded.
27. Device according to claim 25 or 26, characterized in that the code comparison $Ca - Cb$ is carried out locally.
28. Device according to one of claims 25 to 27, characterized by a corresponding identification medium IM of an authorized person which contains the reference code Cb of the person and further information for encoded communication (40) with a corresponding reading station WR.
29. Device according to claim 28, characterized in that the actual code Ca is transmitted to the identification medium IM and that the code comparison with the reference code Cb is carried out by means of the processor (42) of the identification medium IM.



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30. Device according to claim 25, characterized by a master system (47) with a main processor and with a data bank (48) for reference codes Cb and with local function stations (46).
- 5 31. Identification medium IM for an authorized person with a stored reference code Cb of the person, which code is determined with a method according to one of claims 1 to 24, for encoded communication (40) with a corresponding reading station WR.
32. Identification medium according to claim 31 with access and function authorizations for corresponding function stations (46).