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(54) **DAUBECHIES WAVELET TRANSFORM OF IRIS IMAGE DATA FOR USE WITH IRIS RECOGNITION SYSTEM**

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(75) Inventor: **SEONG-WON CHO, SEOUL (KR)**

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Correspondence Address:
KNOBBE MARTENS OLSON & BEAR LLP
2040 MAIN STREET, FOURTEENTH FLOOR
IRVINE, CA 92614 (US)

(57) **ABSTRACT**

(73) Assignee: **SENGA ADVISORS, LLC, BOSTON, MA (US)**

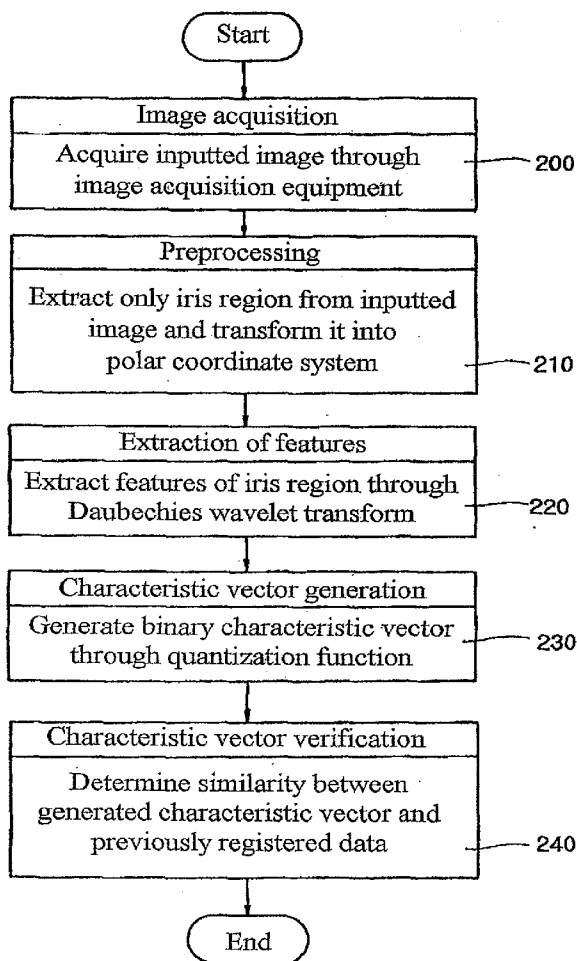
Disclosed is a method of recognizing human iris using Daubechies wavelet transform, wherein the dimensions of characteristic vectors are reduced by extracting iris features from inputted iris image signals through the Daubechies wavelet transform, binary characteristic vectors are generated by applying quantization functions to the extracted characteristic values so that utility of human iris recognition can be improved since storage capacity and processing time thereof can be improved since storage capacity characteristic vectors, and a measurement process suitable for the low capacity characteristic vectors is employed when measuring vectors and previously registered characteristic vectors.

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Related U.S. Application Data

(63) Continuation of application No. 10/656,885, filed on Sep. 5, 2003, now Pat. No. 7,302,087, which is a continuation of application No. PCT/KR01/01303, filed on Jul. 31, 2001.



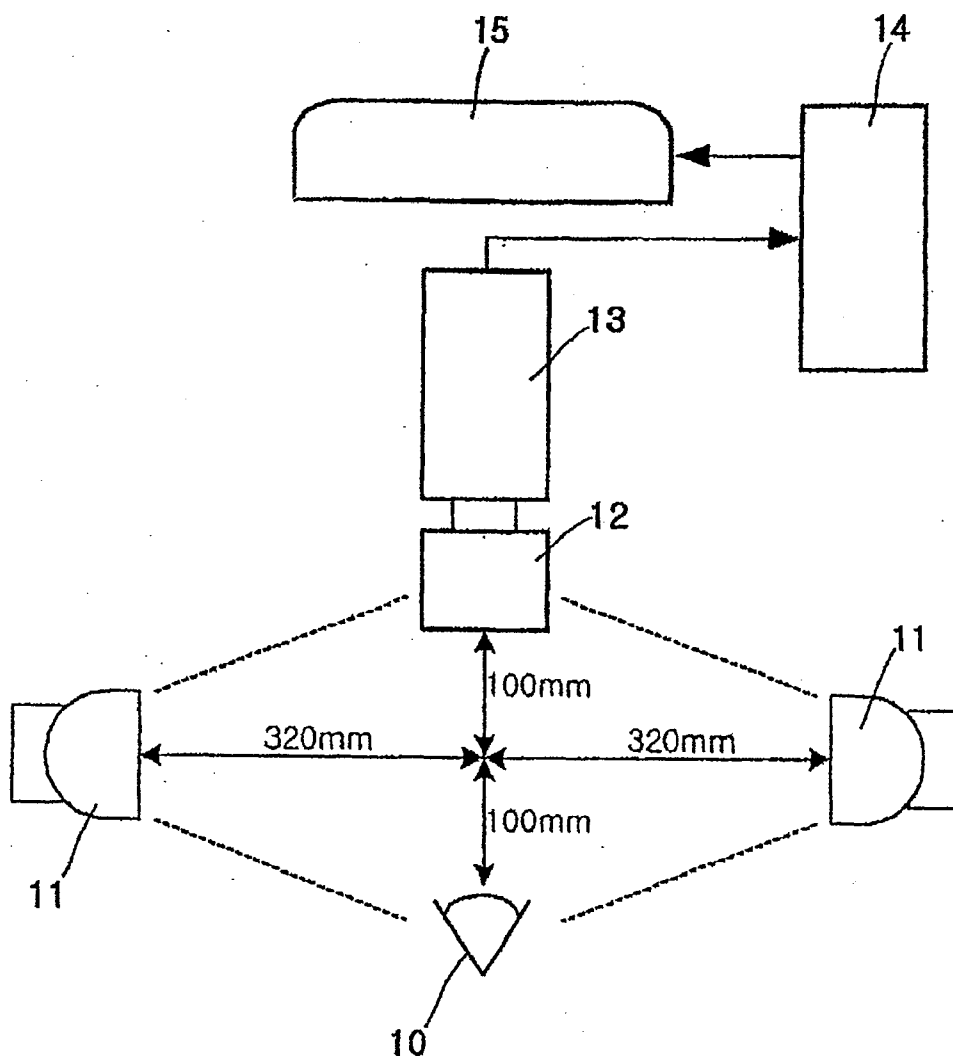


Fig. 1

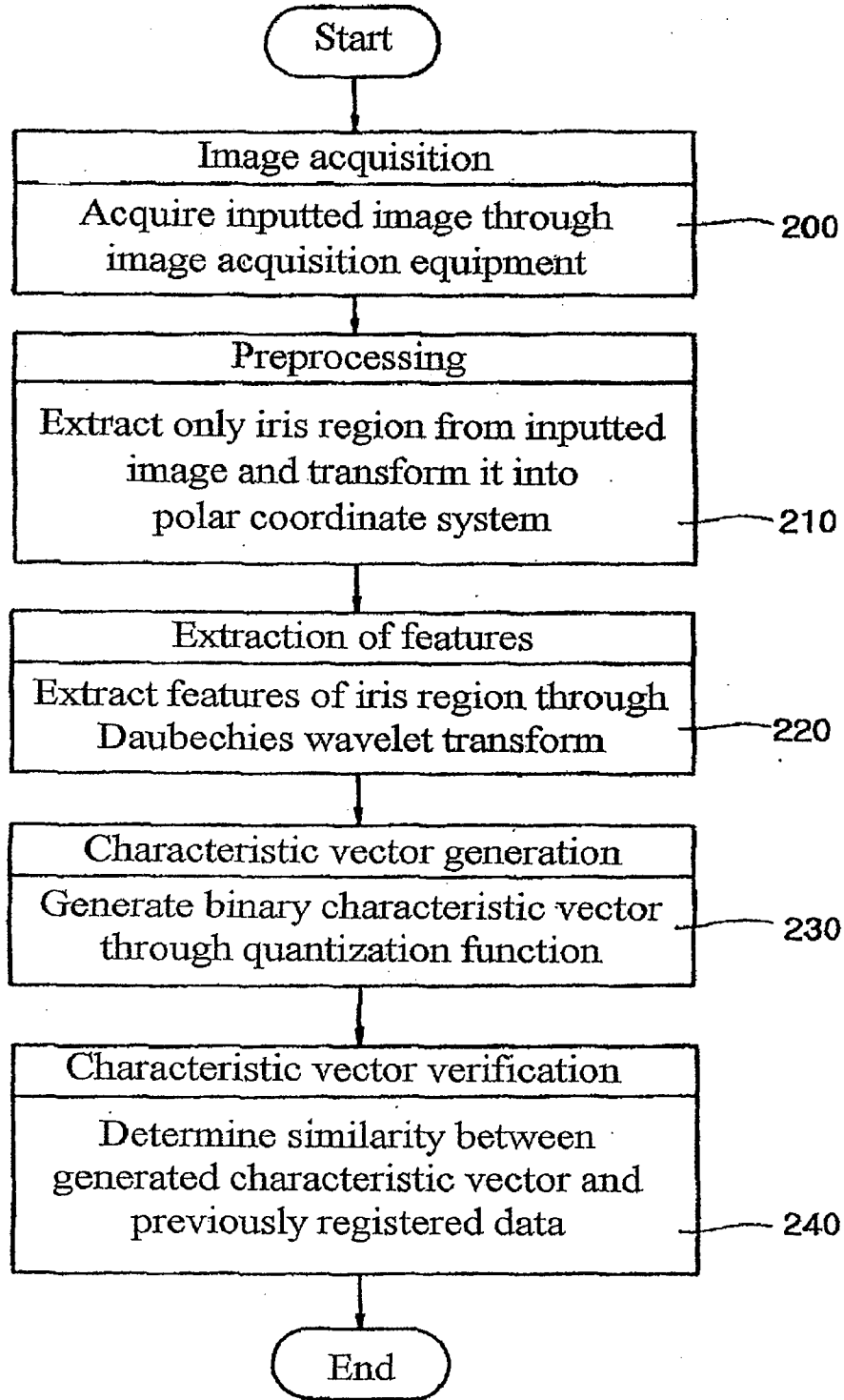


Fig. 2

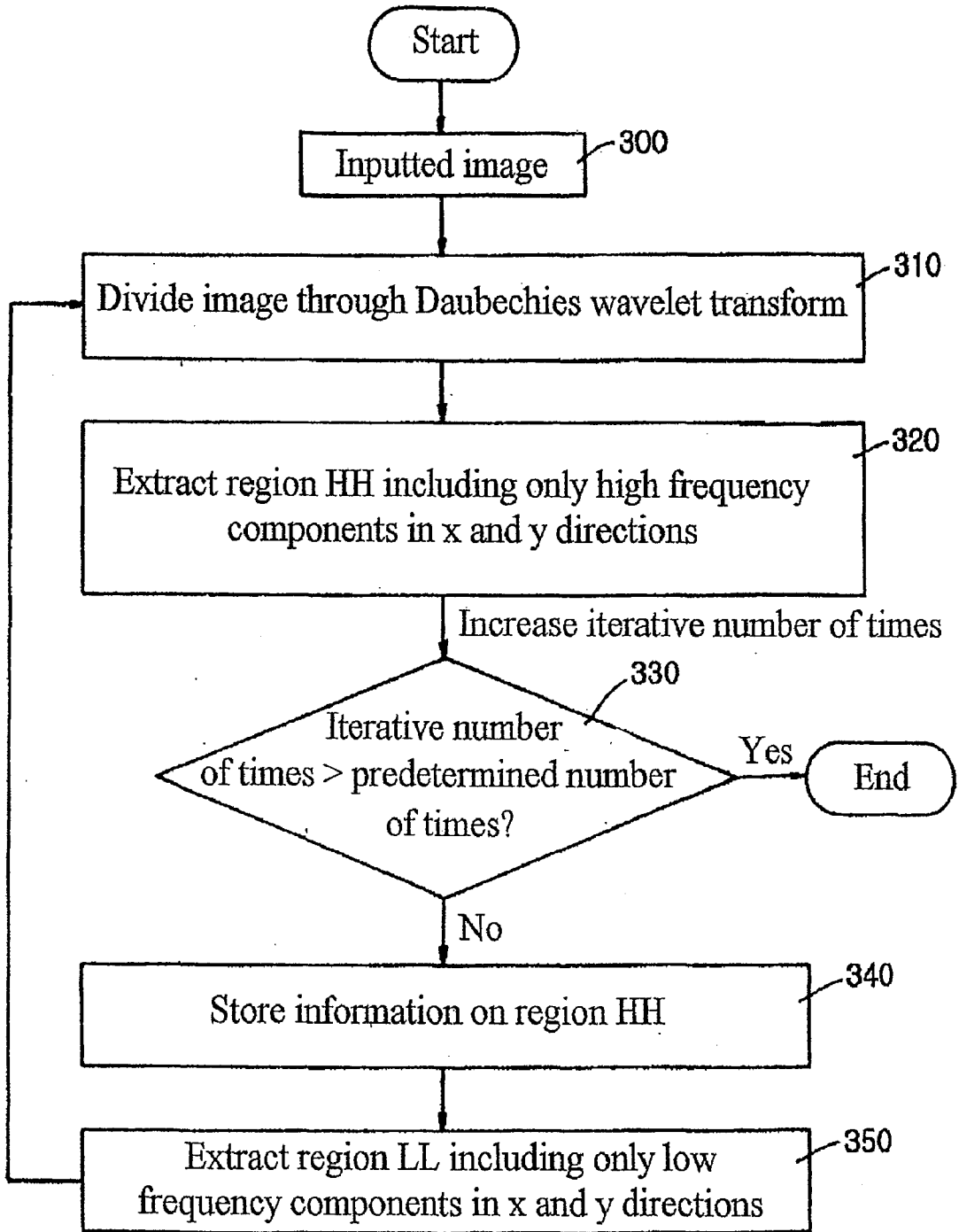


Fig. 3

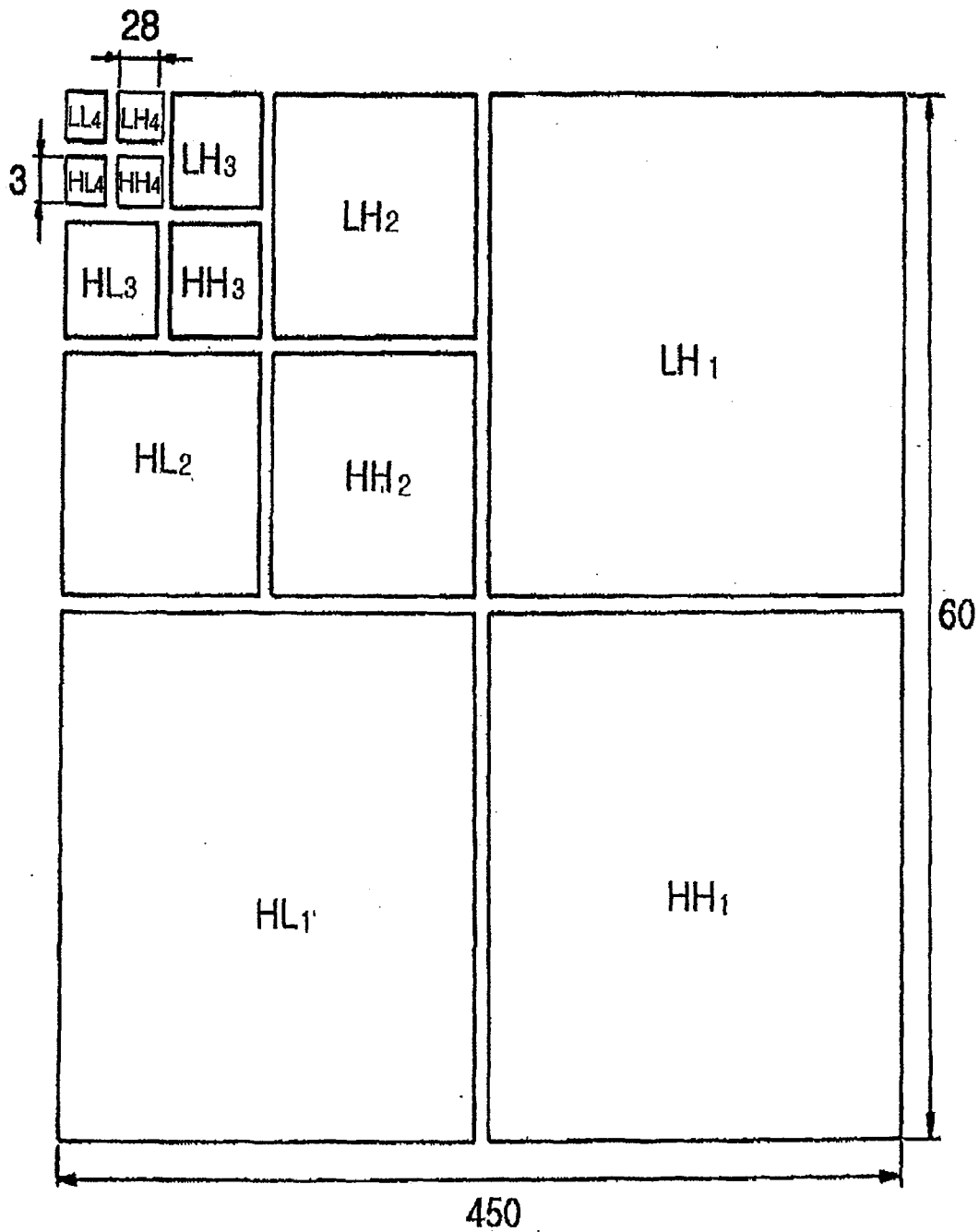


Fig. 4

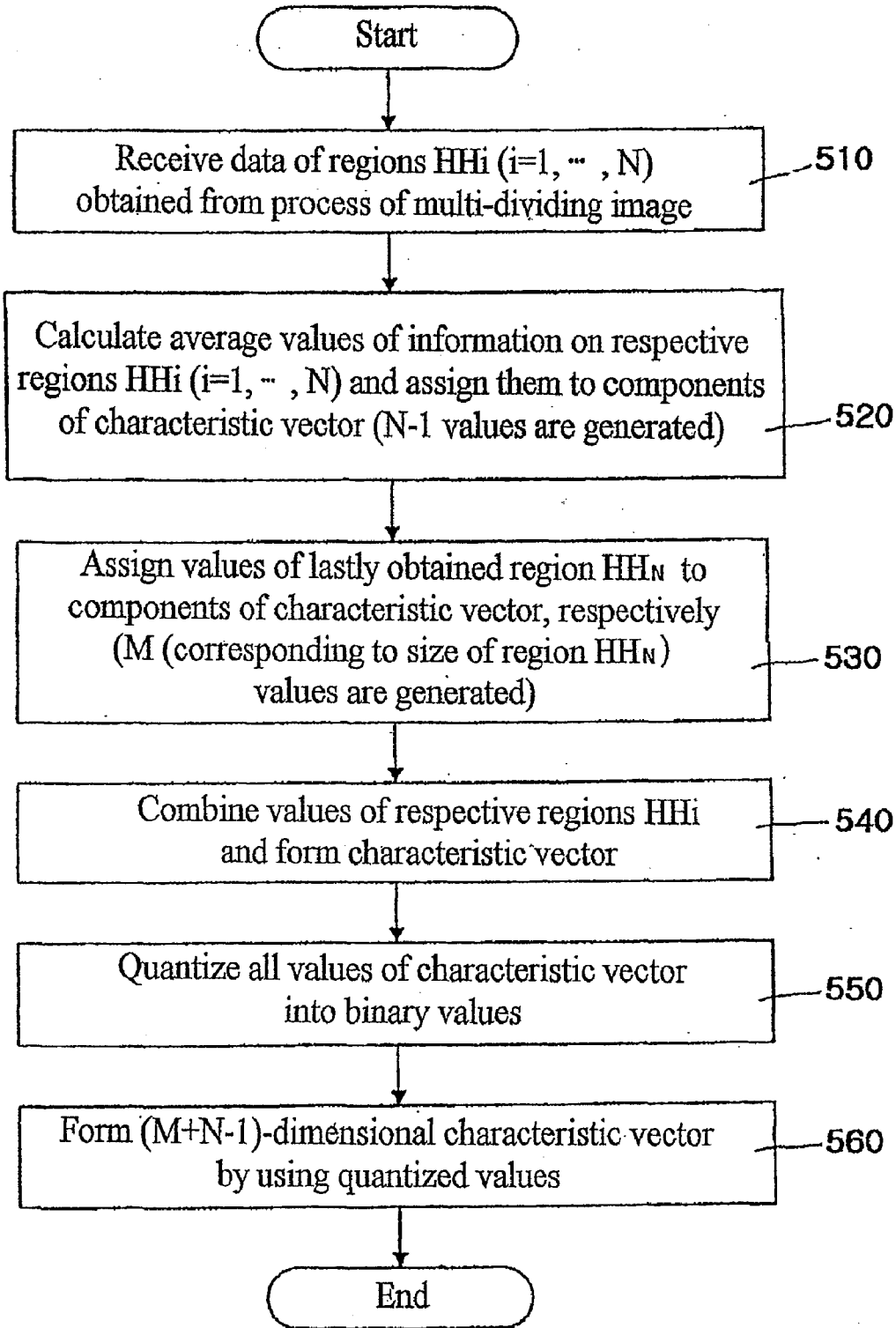
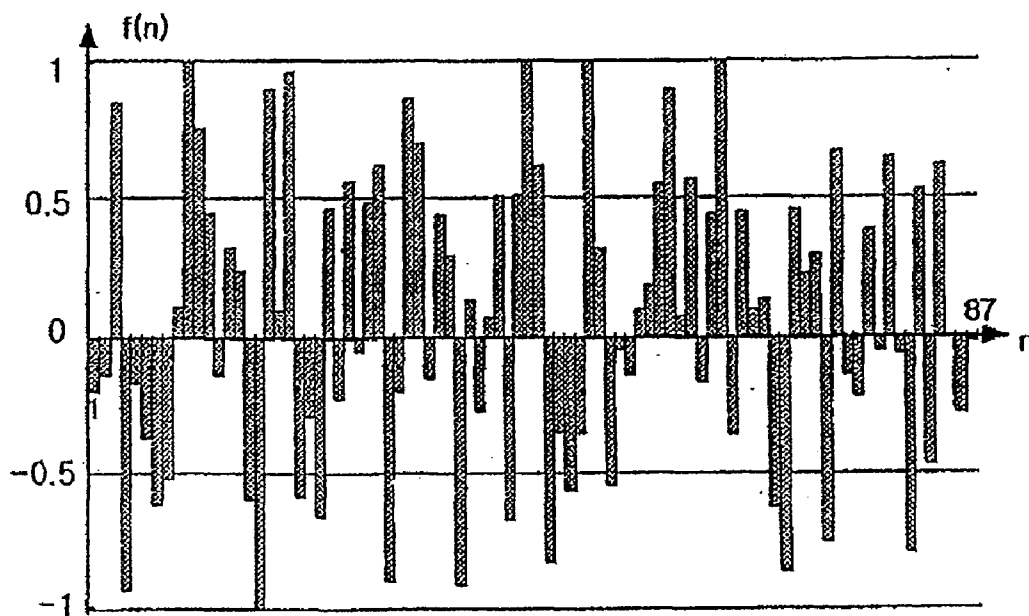


Fig. 5

(a)



(b)

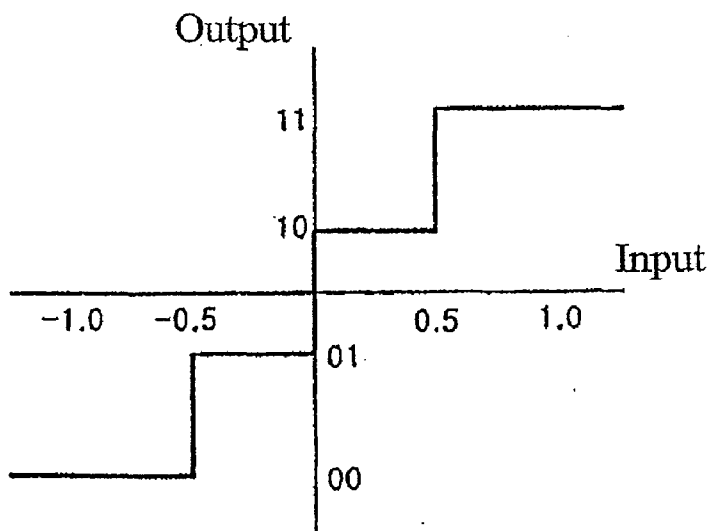


Fig. 6

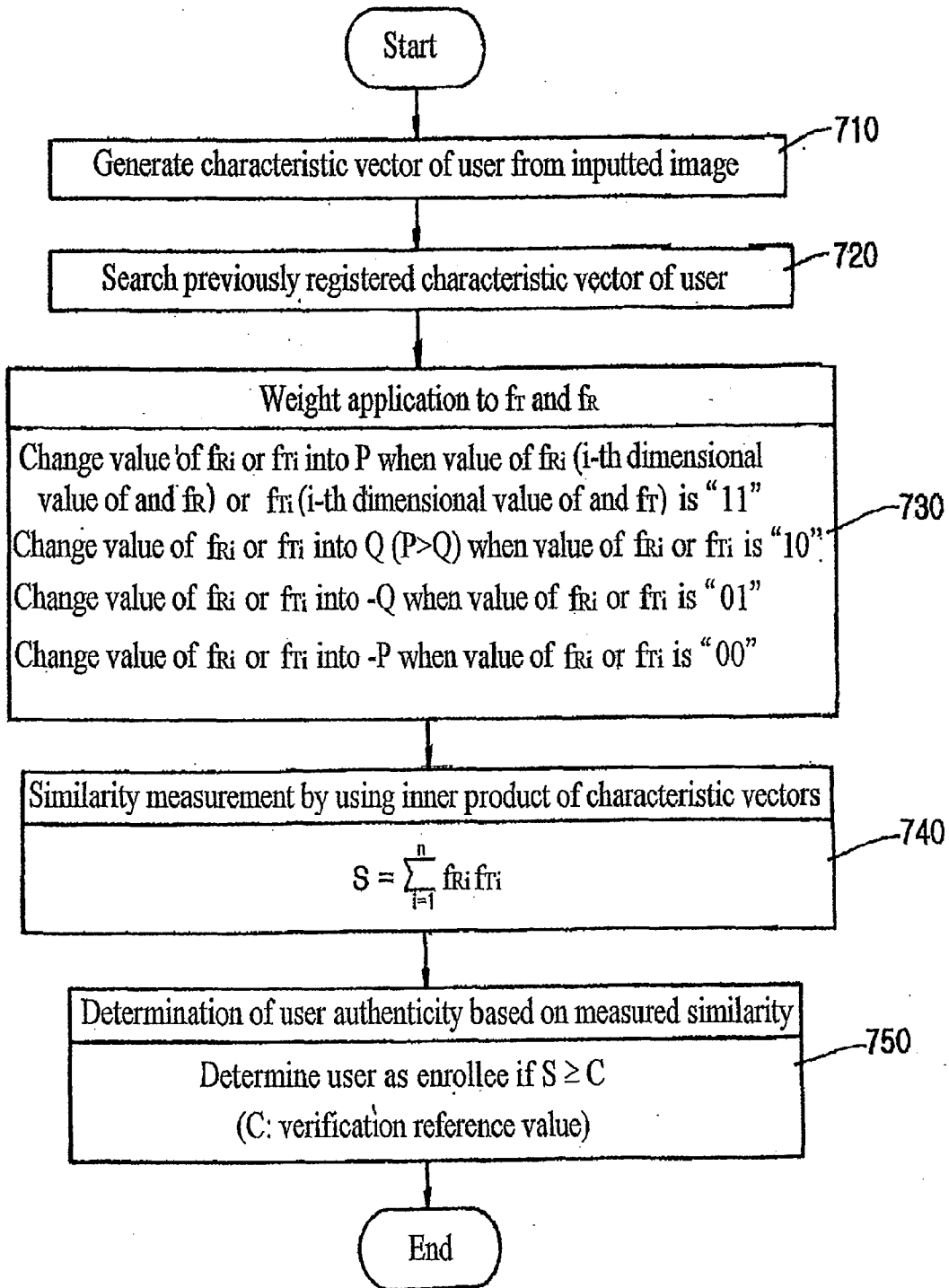


Fig. 7

DAUBECHIES WAVELET TRANSFORM OF IRIS IMAGE DATA FOR USE WITH IRIS RECOGNITION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation application of application Ser. No. 10/656,885, which is a continuation application under 35 U.S.C. §365 (c) claiming the benefit of the filing date of PCT Application No. PCT/KR01/01303 designating the United States, filed Jul. 31, 2001. The PCT Application was published in English as WO 02/071317 A1 on Sep. 12, 2002, and claims the benefit of the earlier filing date of Korean Patent Application No. 2001/11440, filed Mar. 6, 2001. The contents of the Korean Patent Application No. 2001/11440, the international application No. PCT/KR01/01303 including the publication WO 02/071317 A1, and application Ser. No. 10/656,885 are incorporated herein by reference in their entirety.

BACKGROUND

[0002] 1. Field

[0003] The present disclosure relates to a method of processing iris image data, and more particularly, to a method of determining whether an iris image matches the preregistered iris image.

[0004] 2. Discussion of the Related Technology

[0005] An iris recognition system is an apparatus for performing identification of each individual by differentiating iris patterns of the pupil of an eye, which are unique for each individual. It has superior identification accuracy and excellent security as compared with other biometric method using voice and fingerprints from each individual. A human iris is the region between a pupil and a white sclera of an eye, and iris recognition is a technique for performing identification of each individual based on information that is obtained from an analysis of the iris patterns which are different in each individual.

[0006] In general, it is a core technology to efficiently acquire unique characteristic information from input images in the field of an applied technology for performing identification of each individual by utilizing the characteristic information of the human body. A wavelet transform is used to extract characteristics of the iris images, and it is a kind of technique of analyzing signals in multiresolution mode. The wavelet transform is a mathematical theory of formulating a model for signals, systems and a series of processes by using specifically selected signals. These signals are referred to as little waves or wavelets. Recently, the wavelet transform is widely employed in the field of signal and image processing since it has a fast rate as compared with a signal processing algorithm based on the Fourier transform, and it can efficiently accomplish signal localization in time and frequency domains.

[0007] On the other hand, the images, which are obtained by extracting only iris patterns from the iris images acquired by image acquisition equipment and normalizing the patterns at a 450.times.60 size, are used to extract characteristic values through the wavelet transform. Further, a Harr wavelet transform has been widely used in iris recognition, image processing and the like. However, Harr wavelet functions have disadvantages in that the characteristic values are discontinuously and rapidly changed and that high resolution

of the images cannot be obtained in a case where the images are again decompressed after they have been compressed. On the contrary, since Daubechies wavelet functions are continuous functions, the disadvantages of the Harr wavelet functions that the values thereof are discontinuously and rapidly changed can be avoided, and the characteristic values can be extracted more accurately and delicately. Therefore, in a case where the images are to be again decompressed after they have been compressed by using the Daubechies wavelet transform, the images can be restored in high resolution nearer to the original images than when the Harr wavelet transform is used. Since the Daubechies wavelet functions are more complicated than the Han wavelet functions, there is a disadvantage in that more arithmetic quantity may be needed. However, it can be easily overcome by the recent advent of ultrahigh speed microprocessors.

[0008] There is also an advantage in that the Daubechies wavelet transform can obtain fine characteristic values in the process of performing the wavelet transform for extracting the characteristic values. That is, if the Daubechies wavelet transform is used, expression of the iris features can be made in a low capacity of data and extraction of the features can be made accurately.

[0009] Methods of extracting the characteristic values and forming the characteristic vectors by using Gabor transform been mainly used in the iris recognition field. However, the characteristic vectors generated by these methods are formed to have 256 or more dimensions, and they have at least 256 bytes even though it is assumed that one byte is assigned to one dimension. Thus, there is a problem in that practicability and efficiency can be reduced when it is used in the field where low capacity information is needed. Accordingly, it is necessary to develop a method of forming the low capacity characteristic vectors wherein processing, storage, transfer, search, and the like of the pattern information can be efficiently made. In addition, since a simple method of measuring a distance such as a Hamming distance (HD) between two characteristic vectors (characteristic vectors relevant to the input pattern and stored reference characteristic vectors) is used for pattern classification in U.S. Pat. No. 5,291,560, there are disadvantages in that formation of the reference characteristic vectors through generalization of the pattern information cannot be easily made and information characteristics of each dimension of the characteristic vectors cannot be properly reflected.

[0010] That is, in the method of using the Hamming distance in order to verify the two characteristic vectors generated in the form of binary vectors, bit values assigned according to respective dimensions are compared with each other. If they are identical to each other, 0 is given; and if they are different from each other, 1 is given. Then, a value divided by the total number of the dimensions is obtained as a final result. The method is simple and useful in discriminating a degree of similarity between the characteristic vectors consisted of binary codes. When the Hamming distance is used, the comparison result of all the bits becomes 0 if identical data are compared with each other. Thus, the result approaching to 0 implies that the data belong to the persons themselves. If the data do indeed belong to the person, the probability of a degree of similarity will be 0.5. Thus, upon comparison with the other person's data, it is understood that the values converge around 0.5. Accordingly, a proper limit set between 0 and 0.5 will be a boundary for differentiating the data of the persons themselves from the other person's data. The Ham-

ming distance (HD) is excellent in performance thereof in a case where the information is obtained from the extracted iris features by subdividing the data, but it is not suitable when low capacity data is to be used.

[0011] The foregoing discussion in the background section is to provide general background information and does not constitute an admission of prior art.

SUMMARY

[0012] One aspect of the invention provides a method of processing iris image data, which comprise: providing data of an iris image for processing; processing the iris image data so as to provide a reduced iris image data, wherein processing includes conducting a Daubechies wavelet transform multiple times, wherein the reduced iris image data has a smaller size than the iris image data and has a smaller amount of high frequency components than the iris image data; creating a characteristic vector of the iris image using the reduced image data; providing a reference characteristic vector of iris image of a preregistered person; and determining whether the iris image is associated with the preregistered person, using the characteristic vector and the reference characteristic vector.

[0013] In the foregoing method, processing may comprise computing an inner product of the reference characteristic vector and the characteristic vector of the iris image; comparing the inner product against a predetermined threshold value; and determining that the iris image is associated with the predetermined person when the inner product is greater than the predetermined threshold value. Creating the characteristic vector may use quantized pixel values of the reduced iris image data. The quantized pixel values may comprise at least two positive values and at least two negative values. The quantized pixel values may comprise one of the at least two positive values has the same absolute value as one of the at least two negative values. The quantized pixel values may comprise a first positive value and a second positive value, wherein the second positive value is greater than two times of the first positive value.

[0014] Still in the foregoing method, conducting each Daubechies wavelet transform may produce a plurality data representing transformed images, wherein processing may further comprise selecting one from the plurality of transformed image data. The reduced iris image data may be one of the plurality of transformed image data created in the last Daubechies wavelet transform. Creating the characteristic vector may use results of the Daubechies wavelet transforms in addition to the reduced iris image data. Creating the characteristic vector may use at least one non-selected transformed image data in addition to the reduced iris image data. The characteristic vector may comprise substantially more information representing the reduced iris image data than information representing the at least one non-selected transformed image data.

[0015] Yet in the foregoing method, each of the plurality of transformed image data may be classified one of HH, HL, LH and LL, wherein HH represents high frequency components in a first direction and a second direction in the transformed image, the first and second directions being perpendicular to each other, wherein HL represents a high frequency component in the first direction and a low frequency component in the second direction, wherein LH represents a low frequency component in the first direction and a high frequency component in the second direction, and wherein LL represents low frequency components in the first and second directions,

wherein LL is selected among HH, HL, LH and LL for following Daubechies wavelet transform. An average value of the piece of transformed image data classified as HH may be included in the characteristic vector. A total number of the Daubechies wavelet transform is N, wherein the characteristic vector may comprise an N-1 number of values representing the HH data pieces. The number of the multiple times may be from 2 to 7. The number of the plurality of times may be from 4.

[0016] Another aspect of the invention provides an iris image data processing apparatus, comprising at least one integrated circuit programmed to perform the foregoing method.

[0017] In the foregoing apparatus, processing may comprise: computing an inner product of the reference characteristic vector and the characteristic vector of the iris image; comparing the inner product against a predetermined threshold value; and determining that the iris image is associated with the predetermined person when the inner product is greater than the predetermined threshold value. Creating the characteristic vector may use quantized pixel values of the reduced iris image data, and wherein the quantized pixel values may comprise at least two positive values and at least two negative values. Conducting each Daubechies wavelet transform may produce a plurality data representing transformed images, wherein processing may further comprise selecting one from the plurality of transformed image data, and wherein the reduced iris image data is one of the plurality of transformed image data created in the last Daubechies wavelet transform.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 is a view showing the constitution of image acquisition equipment used for performing an iris recognition method according to an embodiment of the present invention.

[0019] FIG. 2 is a flowchart showing procedures for verifying an iris image according to an embodiment of the present invention.

[0020] FIG. 3 is a flowchart showing procedures for multi-dividing the iris image through Daubechies wavelet transform according to an embodiment of the present invention.

[0021] FIG. 4 shows an example of multi-dividing the iris image through the Daubechies wavelet transform.

[0022] FIG. 5 is a flowchart showing procedures for forming a characteristic vector of the iris image based on data acquired from the procedures of multi-dividing the iris image according to an embodiment of the present invention.

[0023] FIG. 6a shows a distribution example of characteristic values of the extracted iris image.

[0024] FIG. 6b shows a quantization function for generating binary characteristic vector from the distribution example of FIG. 6a.

[0025] FIG. 7 is a flowchart showing procedures for determining user authenticity through a similarity measurement between the characteristic vectors.

DETAILED DESCRIPTION OF EMBODIMENTS

[0026] Hereinafter, various embodiments of the present invention will be explained in detail with reference to the accompanying drawings.

[0027] FIG. 1 shows the constitution of image acquisition equipment for use in a method of recognizing a human iris according to an embodiment of the present invention. Refer-

ring to FIG. 1, the constitution of the iris image acquisition equipment will be explained. The image acquisition equipment for use in the method of recognizing the human iris according to an embodiment of the present invention comprises a halogen lamp 11 for illuminating the iris in order to acquire clear iris patterns, a CCD camera 13 for photographing an eye 10 of a user through a lens 12, a frame grabber 14 connected to the CCD camera 12 for acquiring an iris image, and a monitor 15 for showing the image, which are currently inputted to the camera, to the user so that acquisition of correct images and positioning convenience of the user can be obtained when images are acquired.

[0028] According to the constitution of the image acquisition equipment, the CCD camera is used to acquire the image, and iris recognition is made through a pattern analysis of iridial folds. However, in a case where the iris image is acquired indoors by using an ordinary illuminator, it is difficult to extract desired pattern information since the iris image is generally gloomy. Additional illuminators therefore are used so that the information on the iris image cannot be lost. In such a case, loss of the iris pattern information and deterioration of recognition capability due to reflective light should be prevented, and proper illuminators are utilized so that a clear iris pattern can be obtained. In one embodiment of the present invention, the halogen lamp 11 having strong floodlighting effects is used as a main illuminator so that the iris pattern can be clearly shown. Further, as shown in FIG. 1, the loss of the iris image information and eye fatigue of the user can be avoided by placing the halogen lamp illuminators on the left and right sides of the eye in order to cause the reflective light from the lamp to be formed on outer portions of the iris region.

[0029] FIG. 2 is a flowchart showing procedures for verifying the iris image according to an embodiment of the present invention. Referring to FIG. 2, an eye image is acquired through the image acquisition equipment as mentioned above in step 200. In step 210, images of the iris regions are extracted from the acquired eye image through pre-processing and transformed into a polar coordinate system, and the transformed iris pattern is inputted to a module for extracting the features. In step 220, the Daubechies wavelet transform of the inputted iris pattern transformed into the polar coordinate system is performed, and the features of the iris regions are then extracted. The extracted features have real numbers. In step 230, a binary characteristic vector is generated by applying K-level quantization function to the extracted features. In step 240, similarity between the generated characteristic vector and previously registered data of the user is measured. Through the similarity measurement, user authenticity is determined and then verification results are shown.

[0030] In a case where the features of the iris regions are extracted by performing the Daubechies wavelet transform as described above, the Daubechies wavelet function having eight, sixteen or more coefficients can extract more delicate characteristic values than the Daubechies wavelet function having four coefficients, even though the former is more complicated than the latter. Although the Daubechies wavelet function having eight or more coefficients has been used and tested in an embodiment of the present invention, greater performance improvement was not obtained from an embodiment of the present invention and arithmetic quantity and processing time are increased, as compared with a case where the Daubechies wavelet function having four coefficients has

been used and tested. Thus, the Daubechies wavelet function having four coefficients has been used for extracting the characteristic values.

[0031] FIG. 3 is a flowchart showing procedures for multi-dividing the iris image by performing the Daubechies wavelet transform according to an embodiment of the present invention, and FIG. 4 shows an image divided through the Daubechies wavelet transform. Referring to FIGS. 3 and 4, in an embodiment of the present invention, the Daubechies wavelets among various mother wavelets are used to perform extraction of the iris image characteristics. As shown in FIG. 4, when "L" and "H" are respectively used to indicated low frequency and high frequency components, the term "LL" means a component that has passed through a low-pass filter (LPF) in all x and y directions whereas a term "HH" means a component that has passed through a high-pass filter (HPF) in the x and y directions. Furthermore, subscript numerals signify image-dividing stages. For example, "LH₂" means that the image has passed through the low-pass filter in the x direction and through the high-pass filter in the y direction during 2-stage wavelet division.

[0032] In step 310, the inputted iris image is multi-divided by using the Daubechies wavelet transform. Since the iris image is considered as a two-dimensional signal in which one-dimensional signals are arrayed in the x and y directions, quarterly divided components of one image is extracted by passing through the LPF and HPF in all x and y directions in order to analyze the iris image. That is, one two-dimensional image signal is wavelet-transformed in vertical and horizontal directions, and the image is divided into four regions LL, LH, HL, and HH after the wavelet transform has been performed once. At this time, through the Daubechies wavelet transform, the signal is divided into a differential component thereof that has passed through the high-pass filter, and an average component that has passed through the low-pass filter

[0033] Alternatively, performance of the iris recognition system is evaluated in view of two factors; a false acceptance rate (FAR) and a false rejection rate (FRR). Here, the FAR means a probability that entrance of unregistered persons (imposters) may be accepted due to false recognition of unregistered persons as registered ones, and the FRR means a probability that entrance of registered persons (enrollees) is rejected due to false recognition of the registered persons as unregistered ones. For reference, when the method of recognizing the human iris using the Daubechies wavelet transform according to an embodiment of the present invention is employed, the FAR has been reduced from 5.5% to 3.07% and the FRR has also been reduced from 5.0% to 2.25%, as compared with the method of recognizing the human iris using the Harr wavelet transform.

[0034] In step 320, a region HH including only high frequency components in the x and y directions is extracted from the divided iris image.

[0035] In step 330, after increasing the iterative number of times of dividing the iris image, the processing step is completed when the iterative number is greater than a predetermined number. Alternatively, if the iterative number is lower than the predetermined number, the information on the region HH is stored as information for extracting the iris features in step 340.

[0036] Further, in step 350, a region LL comprising only low frequency components in the x and y directions is extracted from the multi-divided iris image. Since the extracted region LL (corresponding to the image reduced in a

fourth size as compared with the previous image) includes major information on the iris image, it is provided as an image to be newly processed so that the wavelet transform can be again applied to the relevant region. Thereafter, the Daubechies wavelet transform is repeatedly performed from step 310.

[0037] On the other hand, in a case where the iris image is transformed from the Cartesian coordinate system to polar coordinate system, in order to avoid changes in the iris features according to variations in the size of the pupil, the region between the inner and outer boundaries of the iris is divided into 60 segments in the r direction and 450 segments in the θ direction by varying the angles by 0.8 degrees. Finally, the information on the iris image is acquired and normalized as 450.times.60 ($\theta \times r$) data. Then, if the acquired iris image is once again wavelet-transformed, the characteristics of the 225.times.30 region HH_1 of which size is reduced by half are obtained, namely, the 225.times.30 information is used as a characteristic vector. This information may be used as it is, but a process of dividing the signals is repeatedly performed in order to reduce the information size. Since the region LL includes major information on the iris image, the characteristic values of further reduced regions such as HH_2 , HH_3 and are obtained by successively applying the wavelet transform to respective relevant regions.

[0038] The iterative number, which is provided as a discriminating criterion for repeatedly performing the wavelet transform, is set as a proper value in consideration of loss of the information and size of the characteristic vector. Therefore, in an embodiment of the present invention, the region HH_4 obtained by performing the wavelet transform four times becomes a major characteristic region, and values thereof are selected as components of the characteristic vector. At this time, the region HH_4 contains the information having 84 (=28 \times 3) data

[0039] FIG. 5 is a flowchart showing procedures for forming the characteristic vector of the iris image by using the data acquired from the process of multi-dividing the iris image according to an embodiment of the present invention. Referring to FIG. 5, the information on the n characteristic vector extracted from the above process, i.e., the information on the regions HH_1 , HH_2 , HH_3 , and HH_4 is inputted in step 510. In step 520, in order to acquire the characteristic information on the regions HH_1 , HH_2 and HH_3 excluding the information on the region HH_4 obtained through the last wavelet transform among the n characteristic vector, each average value of the regions HH_1 , HH_2 and HH_3 is calculated and assigned one dimension. In step 530, all the values of the final obtained region HH_4 are extracted as the characteristic values thereof. After extraction of the characteristics of the iris image signals has been completed, the characteristic vector is generated based on these characteristics. A module for generating the characteristic vector mainly performs the processes of extracting the characteristic values in the form of real numbers and then transforming them to binary codes consisting of 0 and 1.

[0040] However, in step 540, the N-1 characteristic values extracted from step 520 and the M (the size of the final obtained region HH) characteristic values extracted from step 530 are combined and (M+N-1)-dimensional characteristic vector is generated. That is, the total 87 data, which the 84 data of the region HH_4 and the 3 average data of the regions HH_1 , HH_2 and HH_3 are combined, are used as a characteristic vector in an embodiment of the present invention.

[0041] In step 550, the values of the previously obtained characteristic vector, i.e., respective component values of the characteristic vector expressed in the form of the real numbers are quantized into binary values 0 or 1. In step 560, the resultant (M+N-1)-bit characteristic vector is generated by the quantized values. That is, according to an embodiment of the present invention, the resultant 87-bit characteristic vector is generated.

[0042] FIG. 6a shows a distribution example of the characteristic values of the extracted iris image. When the values of the 87-dimensional characteristic vector are distributed according to respective dimensions, the distribution roughly takes a shape of FIG. 6a. The binary vector including all the dimensions is generated by the following Equation 1.

$$\begin{aligned} f_n &= 0 \text{ if } f(n) < 0 \\ f_n &= 1 \text{ if } f(n) > 0 \end{aligned} \quad [\text{Equation 1}]$$

[0043] where $f(n)$ is a characteristic value of the n-th dimension and f_n is a value of the n-th characteristic vector.

[0044] When the 87-bit characteristic vector that is obtained by assigning one bit to the total 87 dimensions are generated in order to use a low capacity characteristic vector, improvement of the recognition rate is limited to some extent since loss of the information on the iris image is increased. Therefore, when generating the characteristic vector, it is necessary to prevent information loss while maintaining the minimum capacity of the characteristic vector.

[0045] FIG. 6b shows a quantization function for generating a binary characteristic vector from the distribution example of the characteristic values shown in FIG. 6a. The extracted (M+N-1)-dimensional characteristic vector shown in FIG. 6a is evenly distributed mostly between 1 and -1 in view of its magnitude. Then, the binary vector is generated by applying the K-level quantization function shown in FIG. 6a to the characteristic vector. Since only signs of the characteristic values are obtained through the process of Equation 1, it is understood, that information on the magnitude has been discarded. Thus, in order to accept the magnitude of the characteristic vector, a 4-level quantization process was utilized in an embodiment of the present invention.

[0046] As described above, in order to efficiently compare the characteristic vector generated through the 4-level quantization with the registered characteristic vector, the quantization levels have the weights expressed in the following Equation 2.

$$\begin{aligned} f_n &= 4 \text{ if } f(n) \geq 0.5 \text{ (level 4)} \\ f_n &= 1 \text{ if } 0.5 > f(n) \geq 0 \text{ (level 3)} \\ f_n &= -1 \text{ if } 0 > f(n) > -0.5 \text{ (level 2)} \\ f_n &= -4 \text{ if } f(n) \leq -0.5 \text{ (level 1)} \end{aligned} \quad [\text{Equation 2}]$$

[0047] where f_n means an n-th dimension of the previously registered characteristic vector f_R of the user or the characteristic vector f_T of the user generated from the iris image of the eye image of the user. Explanation of how to use the weights expressed in Equation 2, is as follows.

[0048] In a case where the n-th dimensional characteristic value $f(n)$ is equal or more than 0.5 (level 4), the value of the i-th dimension f_{R_i} or f_{T_i} is converted and assigned 4 if the value is "11". In a case where the n-th dimensional characteristic value $f(n)$ is more than 0 and, less than 0.5 (level 3), the value of the i-th dimension f_{R_i} or f_{T_i} is converted and assigned 1 if

the value is “10”. In a case where the n-th dimensional characteristic value f(n) is more than -0.5 and less than 0 (level 2), the value of the i-th dimension f_{Ri} or f_{Ti} , is converted and assigned -1 if the value is “01”. In a case where the n-th dimensional characteristic value f(n) is equal or less than -0.5 (level 1), the value of the i-th dimension f_{Ri} or f_{Ti} , is converted and assigned -4 if the value is “00”. This is due to the weights being applied to respective values as expressed in Equation 2 as it is suitable for the following verification method of an embodiment of the present invention.

[0049] FIG. 7 is a flowchart showing procedures for discriminating the user authenticity through similarity measurement between the characteristic vectors. Referring to FIG. 7, in step 710, the characteristic vector f_T of the user is generated from the iris image of the eye image of the user. In step 720, the previously registered characteristic vector f_R of the user is searched. In step 730, in order to measure the similarity between the two characteristic vectors, the weights are assigned to the characteristic vectors f_R and f_T depending on the value of the binary characteristic vector based on Equation 2.

[0050] In step 740, an inner product or scalar product S of the two characteristic vectors is calculated and the similarity is finally measured. Among the measures generally used for determining correlation between the registered characteristic vector f_R and the characteristic vector f_T of the user, it is the inner product S of the two characteristic vectors which indicate the most direct association. That is, after the weights have been assigned to the respective data of the characteristic vector in step 730, the inner product S of the two characteristic vectors is used to measure the similarity between the two vectors.

[0051] The following Equation 3 is used for calculating the inner product of the two characteristic vectors.

$$S = \sum_{i=1}^n f_{Ri} \cdot f_{Ti} = (f_{R1} \cdot f_{T1} + f_{R2} \cdot f_{T2} + \dots + f_{Rn} \cdot f_{Tn}). \quad \text{[Equation 3]}$$

[0052] where f_R is the characteristic vector of the user that has been already registered, and f_T is the characteristic vector of the user that is generated from the iris image of the eye of the user.

[0053] According to the above processes, one effect which can be obtained by the quantization according to the sign of the characteristic vector values as in the method in which the binary vector is generated with respect to the values of the characteristic vector extracted from the iris image according to respective dimensions can be maintained. That is, like the Hamming distance, the difference between 0 and 1 can be expressed. In a case where the two characteristic vectors have the same-signed values with respect to the each dimension, positive values are added to the inner product S of the two characteristic vectors. Otherwise, negative values are added to the inner product S of the two vectors. Consequently, the inner product S of the two characteristic vectors increases if the two data belong to an identical person, while the inner product S of the two characteristic vectors decreases if the two data does not belong to an identical person.

[0054] In step 750, the user authenticity is determined according to the measured similarity obtained from the inner product S of the two characteristic vectors. At this time, the

determination of the user authenticity based on the measured similarity depends on the following Equation 4.

$$\text{If } S > C, \text{ then TRUE or else FALSE} \quad \text{[Equation 4]}$$

[0055] where C is a reference value for verifying the similarity between the two characteristic vectors.

[0056] That is, if the inner product S of the two characteristic vectors is equal or more than the verification reference value C, the user is determined as an enrollee. Otherwise, the user is determined as an imposter.

[0057] As described above, the method of recognizing the human iris using the Daubechies wavelet transform according to an embodiment of the present invention has an advantage that FAR and FRR can be remarkably reduced as compared with the method using the Harr wavelet transform, since the iris features are extracted from the inputted iris image signals through the Daubechies wavelet transform.

[0058] Furthermore, in order to verify the similarity between the registered and extracted characteristic vectors f_R and f_T , the inner product S of the two characteristic vectors is calculated, and the user authenticity is determined based on the measured similarity obtained by the calculated inner product S of the two vectors. Therefore, there is provided a method of measuring the similarity between the characteristic vectors wherein loss of the information, which may be produced by forming the low capacity characteristic vectors, can be minimized.

[0059] The foregoing is a mere embodiment for embodying the method of recognizing the human iris using the Daubechies wavelet transform according to an embodiment of the present invention. The present invention is not limited to the embodiment described above. A person skilled in the art can make various modifications and changes to embodiments of the present invention without departing from the technical spirit and scope of the present invention defined by the appended claims.

What is claimed is:

1. A method of processing iris image data, comprising:
 - providing data of an iris image for processing;
 - processing the iris image data so as to provide a reduced iris image data, wherein processing includes conducting a Daubechies wavelet transform multiple times, wherein the reduced iris image data has a smaller size than the iris image data and has a smaller amount of high frequency components than the iris image data;
 - creating a characteristic vector of the iris image using the reduced image data;
 - providing a reference characteristic vector of iris image of a preregistered person; and
 - determining whether the iris image is associated with the preregistered person, using the characteristic vector and the reference characteristic vector.
2. The method of claim 1, wherein processing comprises:
 - computing an inner product of the reference characteristic vector and the characteristic vector of the iris image;
 - comparing the inner product against a predetermined threshold value; and
 - determining that the iris image is associated with the predetermined person when the inner product is greater than the predetermined threshold value.
3. The method of claim 1, wherein creating the characteristic vector uses quantized pixel values of the reduced iris image data.

4. The method of claim 3, wherein the quantized pixel values comprise at least two positive values and at least two negative values.

5. The method of claim 4, wherein the quantized pixel values comprise one of the at least two positive values has the same absolute value as one of the at least two negative values.

6. The method of claim 4, wherein the quantized pixel values comprise a first positive value and a second positive value, wherein the second positive value is greater than two times of the first positive value.

7. The method of claim 1, wherein conducting each Daubechies wavelet transform produces a plurality data representing transformed images, wherein processing further comprises selecting one from the plurality of transformed image data.

8. The method of claim 7, wherein the reduced iris image data is one of the plurality of transformed image data created in the last Daubechies wavelet transform.

9. The method of claim 7, wherein creating the characteristic vector uses results of the Daubechies wavelet transforms in addition to the reduced iris image data.

10. The method of claim 9, wherein creating the characteristic vector uses at least one non-selected transformed image data in addition to the reduced iris image data.

11. The method of claim 10, wherein the characteristic vector comprises substantially more information representing the reduced iris image data than information representing the at least one non-selected transformed image data.

12. The method of claim 7, wherein each of the plurality of transformed image data is classified one of HH, HL, LH and LL, wherein HH represents high frequency components in a first direction and a second direction in the transformed image, the first and second directions being perpendicular to each other, wherein HL represents a high frequency component in the first direction and a low frequency component in the second direction, wherein LH represents a low frequency component in the first direction and a high frequency component in the second direction, and wherein LL represents low frequency components in the first and second directions,

wherein LL is selected among HH, HL, LH and LL for following Daubechies wavelet transform.

13. The method of claim 12, wherein an average value of the piece of transformed image data classified as HH is included in the characteristic vector.

14. The method of claim 13, wherein a total number of the Daubechies wavelet transform is N, wherein the characteristic vector comprises an N-1 number of values representing the HH data pieces.

15. The method of claim 1, wherein the number of the multiple times is from 2 to 7.

16. The method of claim 1, wherein the number of the plurality of times is from 4.

17. An iris image data processing apparatus, comprising at least one integrated circuit programmed to perform the method of claim 1.

18. The apparatus of claim 17, wherein processing comprises:

- computing an inner product of the reference characteristic vector and the characteristic vector of the iris image;
- comparing the inner product against a predetermined threshold value; and

determining that the iris image is associated with the predetermined person when the inner product is greater than the predetermined threshold value.

19. The apparatus of claim 17, wherein creating the characteristic vector uses quantized pixel values of the reduced iris image data, and wherein the quantized pixel values comprise at least two positive values and at least two negative values.

20. The apparatus of claim 17, wherein conducting each Daubechies wavelet transform produces a plurality data representing transformed images, wherein processing further comprises selecting one from the plurality of transformed image data, and wherein the reduced iris image data is one of the plurality of transformed image data created in the last Daubechies wavelet transform.

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