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(54) Method and apparatus for authenticating documents

(57) In a method and apparatus for authenticating documents, at least one small area (22) on a document (12) being tested is sensed by a spectroscope (26), and the light intensity at a plurality (e.g. 50) of spectral points is measured by a photodiode array (30). The resulting signals are digitized in an analog-to-digital converter (38) and the resulting data is stored. This data is then analyzed by discriminant analysis, whereby the intensity values treated as components of a vector are multiplied by one or more sets of weighting coefficients (discriminant functions) to provide a set of discriminant function values. A distance measurement between this set of values and the centroid of a corresponding set of values for genuine documents is compared with a threshold value to determine the authenticity of the document (12).

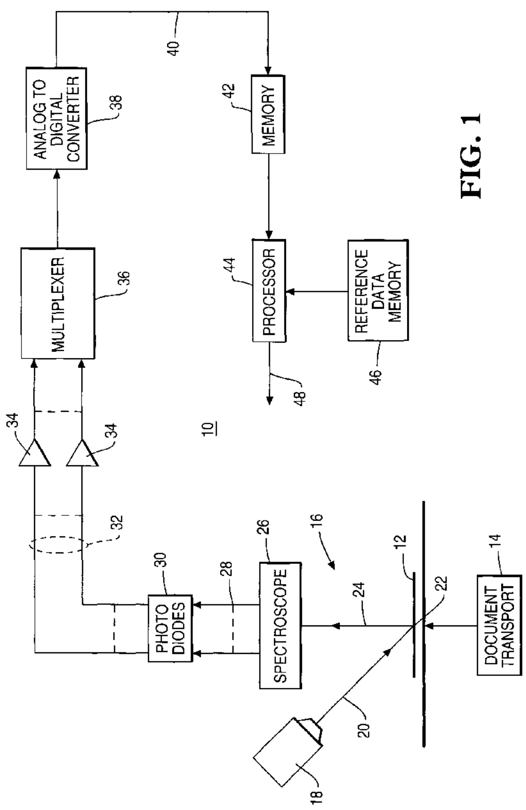

FIG. 1

EP 0 744 716 A2

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Description

This invention relates to a method and apparatus for authenticating documents.

Automatic machines which accept banknotes and other valuable documents such as cheques are becoming more widely used. It is important for such machines to authenticate the documents, that is, to distinguish between genuine and counterfeit documents.

U.K. Patent Application No. GB-A-2 192 275 discloses a system for authenticating banknotes by detecting colours thereof by reflected or transmitted light. Optical fibre bundles direct light from a light source onto the banknote, and the reflected or transmitted light is incident on a plurality of colour filters which pass the light they transmit to respective further optical fibres which transmit the light to respective photosensors. The output signals from the photosensors are analysed to determine the authenticity of the banknote, by comparing data representing the detected signals or signal ratios with corresponding reference data derived from a genuine banknote. This known system is based on a comparison technique and has the disadvantage of requiring the storage of large amounts of reference data.

It is an object of the present invention to provide a method and apparatus for authenticating documents, which is capable of authenticating documents in an efficient manner, yet requires only a small amount of stored reference data.

Therefore, according to the present invention, there is provided a method of determining the authenticity of a document, characterized by the steps of: dispersing light derived from an area of said document into a spectrum, generating a plurality of electrical signals representing light intensity values in a corresponding plurality of spectral wavebands in said spectrum, storing data representing said electrical signals, and analyzing the stored data by discriminant analysis to determine the authenticity of said document.

It is found that the use of discriminant analysis to determine the authenticity of documents results in good classification of documents as authentic or non-authentic, with only a low rate of misclassification, while involving the storage of only a low quantity of reference data.

One embodiment of the present invention will now be described by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a diagram of a document authentication system according to the present invention;

Fig. 2 is a plot illustrating the classification of documents; and

Fig. 3 is a flowchart showing the process utilized by the system shown in Fig. 1 for determining the authenticity of a document.

Referring to Fig. 1, there is shown a simplified block diagram of a document authentication system 10. A document 12, whose authenticity is to be determined, is fed by document transport means 14 to a sensing station 16, where the document 12 is maintained in a stationary state for a time sufficient to sense the document in a manner to be described. Alternatively, the document could be placed manually in the sensing station 16. Located at the sensing station 16 is a broadband (white) light source 18 which directs a narrow, collimated beam of light over a light path 20 to illuminate a small circular area 22 on the document 12. Light from the area 22 passes via a light path 24 to a spectroscope 26 which disperses the incident light into a spectrum output beam 28, in the wavelength range of from 400 to 900nm, for example. The spectroscope 26 may be a standard, commercially available spectroscope.

The dispersed light beam 28 is applied to a photodiode array 30. The number of photodiode in the array 30 may depend on the application. In one example, 50 photodiodes are produced, thereby producing electrical signals representing incident light intensity on a corresponding number of output lines 32, which are connected via respective amplifiers 34 to a multiplexer 36. However, the number of photodiodes 30 is not a limitation, and more, or fewer, than 50 photodiodes may be utilized. Also, signals derived from a relatively large number e.g. 250, of sensors, may be compressed by using a computer program to a smaller number, e.g. 50, of points per spectrum. It is found that good classification results may be achieved with as few as 15 spectral points, for example.

The output of the multiplexer 36 is applied to an analog-to-digital converter 38 which provides, on a serial output 40, digital data representing the light intensities incident on the respective photodiodes of the photodiode array 30. This data is stored in a memory 42 which is connected to a processor 44 which processes the data using the statistical technique of discriminant analysis, in a manner to be described, utilizing reference data stored in a memory 46, and provides an output signal on a line 48, identifying the document 12 as genuine or counterfeit.

As mentioned, the processor 44 operates on the data in accordance with the statistical technique of discriminent analysis. It is assumed that the documents being tested for authenticity are all of the same document type. For example, if the documents are banknotes, it is assumed that the banknotes are all issued by the same issuing bank and are of the same denomination, for instance, the documents 12 may be Bank of England ten pound notes. It will be appreciated that if the apparatus 10 is located in a machine capable of accepting various types of banknotes, for example, then an initial recognition step may be required to recognize the document type, and provide a signal to access the appropriate reference data stored in the memory 46.

Samples of the particular document type, e.g. Bank of England ten pound notes, are utilized in a preliminary procedure to calculate discriminant functions for use in the reference data memory 46. In one embodiment, it is assumed that banknotes of three classes, namely genuine notes, colour photocopied notes and forged notes (other than colour photocopied notes) are available, wherein forged notes have been produced by printing procedures more sophisticated than colour photocopying. In one example, 200 genuine notes, 100 colour photocopied notes, and 15 forged notes were utilized, although these figures are not a limitation and other numbers of samples may be utilized. The colour photocopied notes and the forged notes are examples of counterfeit notes. All the sample notes are fed in turn to a sensing station, similar to the sensing station 16 (Fig. 1), and digital light intensity samples at the same number of spectrum sampling points are produced in a manner similar to that described with reference to Fig. 1, resulting in stored data which can be regarded mathematically as a vector corresponding to each banknote sample, the vectors having 50 components i.e. being vectors in 50-dimensional space. If these vectors are regarded as points in such 50-dimensional space, it should be understood that the points corresponding to the class of genuine notes are clustered together, the points corresponding to the class of colour photocopied notes are clustered together, and the points corresponding to the class of forged notes are clustered together. Thus, there are three classes of clustered points.

A description of the statistical technique of discriminant analysis can be found, for example, in the book by R.O. Duda and P.E. Hart: "Pattern Classification and Scene Analysis," John Wiley & Sons, 1973, at pages 114-121. Briefly, the technique aims at "projecting" the points in the high (e.g. 50) dimensional space to a lower dimensional space which is of a dimension one less than the number of classes, i.e. where there are three classes, to two-dimensional space, while retaining a high degree of clustering, corresponding to the original clustering. For this purpose, functions are computed which maximize the ratio of between-class scatter to within-class scatter. Thus, for example, the projection from 50-dimensional space to 2-dimensional space is accomplished by two discriminant functions. Mathematically, this corresponds to the equations:-

$$y_1 = \sum_{i=1}^{50} w_{i1} x_i$$

$$y_2 = \sum_{i=1}^{50} w_{i2} x_i$$

where the x_i (i=1,...,50) are the digitized spectral intensity components, w_{il} (i=1,..,50) and w_{i2} (i=1,...50) are the two sets of discriminant function coefficients, and y_1 and y_2 are the projected discriminant function values in 2-dimensional space of the 50-dimensional vector x_i (i=1,...,50). A procedure for computing discriminant functions is set forth in the aforementioned Duda and Hart textbook reference, for example. The discriminant functions w_{i1} and w_{i2} (i=1,...,50) are stored.

It will be appreciated that each sample note gives rise to corresponding discriminant function values (y_1, y_2) in 2-dimensional space. The next step in the procedure is to calculate the mean (centroid) discriminant function values for the genuine notes. Referring to Fig. 2, there is shown a plot of discriminant function values (y_1, y_2) for the various sample notes. The discriminant function values for the genuine sample notes are shown as small solid circular areas; the discriminant function values for the colour photocopied sample notes are shown as crosses; and the discriminant function values for the forged sample notes are shown as small outline circles. It is seen that the discriminant function values are disposed in three clusters 60, 62 and 64, corresponding to the genuine sample notes, the color photocopied sample notes and the forged sample notes respectively. It will be appreciated that Fig. 2 is simplified by not showing the full number of discriminant function values, for clarity. However, the clustering of the discriminant function values in three clusters 60,62 and 64 is clearly seen.

Next, the mean (centroid) values (m_1,m_2) of the discriminant function values for the genuine notes in the cluster 60 are calculated and stored. These values are represented by the point 66 shown in the plot of Fig. 2.

It should be understood that there has now been computed, and stored, reference data in the form of the discriminant function coefficients w_{i1} (i = 1,...,50) and w_{i2} (i = 1,...,50) and the mean discriminant function values (m_1, m_2) for the genuine notes. Also, a threshold value T (to be explained) is entered and included in the reference data. This reference data may now be transferred to the memory 46, contained in the authentication system 10, Fig. 1 for testing the authenticity of an unknown banknote. For example, the reference data may be stored on a diskette which is transported to the location where an authentication system 10 (Fig. 1) is installed. Copies of such diskette could be utilized to transfer the reference data to any locations where an authentication system such as the system 10 is situated.

The manner in which a document 12 is tested for authenticity will now be described with reference to the flowchart 80 of Fig. 3. First as shown in block 82, light from the small area 22 of the document 12 being tested is dispersed by the spectroscope 26 (Fig. 1), with the dispersed beam being sensed by the photodiodes 30, thereby generating the 50 intensity values which are digitized and stored.

Next, as shown in block 86, the discriminant function values for the note 12 being tested are calculated using the discriminant function coefficients W_{i1} (i=1,..., 50) and W_{i2} (i=1,...,50) stored in the reference data memory 46, thereby providing a pair of values corresponding to a point (y_1, y_2) on the plot shown in Fig. 2. Then, as shown in block 88, the distance of this point from the centroid discriminant function value point 66 is calculated.

Finally, as shown in block 90 a comparison is made as to whether the calculated distance is less than the threshold value T, included in the reference data. If yes, then a signal is produced on the output line 48 (Fig. 1) indicative of the document 12 being authentic (block 92). If no, then the signal on the output line 48 is indicative of the document 12 being counterfeit (block 94). Referring to Fig. 2, it will be appreciated that the distance comparison effectively determines whether or not the point on the plot corresponding to the document 12 being tested lies inside the circle 96 having centre 66 and radius T. If the point lies inside the circle 96, then the document 12 is determined to be authentic. If not, the document is determined to be non-authentic (counterfeit).

It will be appreciated that if the document 12 is determined as non-authentic, the signal on the line 48 may be effective to return the document to an entry slot (not shown) or divert the document to a reject bit (not shown). If the document is determined to be authentic a transaction can be performed. For example, if the document is a banknote, a financial transaction may be initiated.

Modifications of the described embodiment are possible. For example, the number of classes of documents may differ from the three classes utilized in the described embodiment (genuine, colour photocopies, other forged documents). Thus, there may be four classes (new genuine banknotes, used genuine banknotes, colour photocopied banknotes, other forged banknotes). In this case there will be three discriminant functions, instead of two, and instead of the two-dimensional plot (Fig. 2) a three-dimensional plot will be produced. The new genuine banknotes and used genuine banknotes produce respective clusters of discriminant function values which overlap, and the mean (centroid) of all these discriminant function values is taken as the point corresponding to the point 66 (Fig. 2) from which the distance is measured during the authentication procedure for an unknown document. It will, of course, be appreciated that the circle 96 (Fig. 2) is replaced by a sphere and that authentic documents correspond to points within the sphere.

In another modification, there may be only two classes of documents, namely genuine banknotes (new and used), and counterfeit banknotes (colour photocopied and other forged banknotes). In this modification, there is only one discriminant function and the discriminant function values are arranged in two clusters along a straight line.

It will be appreciated that in the above-described embodiment and modifications, the distance measurement used to determine the distance between the discriminant function values of a document being tested, and the centroid discriminant function values is the standard Euchidean distance measurement. As an alternative, the Mahalanobis distance could be used in which case the decision curve or surface, corresponding to the circle 96 or sphere, discussed above, would be an ellipse or ellipsoid, with a document being characterized as authentic if its calculated discriminant function values correspond to a point inside the ellipse or ellipsoid. The concept of Mahalanobis distance is well known to those skilled in the pattern recognition art. For example, see page 24 of the aforementioned textbook by Duda and Hart for a discussion of the Mahalanobis distance concept.

In yet another modification, instead of single small area of the document 12 (Fig. 1) being tested being used to obtain the light intensity values used in the discriminant analysis procedure described hereinabove, a plurality of such small areas, for example three such areas, located at different points on the document being tested may be utilized. Thus, the light source 18, Fig. 1 may be controlled to direct light successively towards three different small areas of the document 12. Alternatively, if additional equipment were provided, three small areas could be sensed simultaneously. The data dervied from each area would be utilized to provide an authenticity signal, and the three authenticity signals would be utilized, for instance using a majority voting procedure, to categorize the document as authentic if at least two of the signals were indicative of an authentic document. This modification will result in an increased amount of data to be analysed by the discriminant analysis procedure, but more reliable results may be achieved. In yet another modification, the document 12 may be sensed while it is moving. This will require an appropriate control of the photodiode array 30 to provide signals corresponding to a desired small area or areas to be sensed. In another modification light could be directed towards and/or sensed from the document by using optical fibres.

Claims

1. A method of determining the authenticity of a document (12), characterized by the steps of: dispersing light derived from an area (22)of said document (12) into a spectrum, generating a plurality of electrical signals representing light intensity values in a corresponding plurality of spectral wavebands in said spectrum, storing data representing said electrical signals, and analyzing the stored data by discriminant analysis to determine the authenticity of said document

2. A method according to claim 1, characterized in that said step of analyzing the stored data includes the

steps of: calculating discriminant function values utilizing the stored data; determining a distance measurement representing the distance between the calculated discriminant function values and reference discriminant function values, and determining said document as authentic if said distance measurement is less than a predetermined threshold value.

3. A method according to claim 1 or claim 2, characterized in that said distance measurement is a Euclidean distance measurement.

4. A method according to claim 1 or claim 2, characterized in that said distance measurement is a Mahalanobis distance measurement.

5. A method according to any one of claim 2 to 4, characterized in that said reference discriminant function values correspond to centroid discriminant function values derived from genuine documents.

6. A method according to any one of the preceding claims, characterized by the step of utilizing a plurality of areas on said document (12) to generate data representing light intensity values in said plurality of spectral wavelengths.

7. Apparatus for determining the authority of a document (12), characterized by light dispersing means (26) adapted to disperse light derived from an area of said document (12) into a spectrum, light sensing means (30) adapted to provide signals representing light intensity values in a plurality of spectral wavebands in said spectrum, storage means (42) adapted to store data representing said electrical signals, and analyzing means (44) adapted to analyze said data using discriminant anaysis, and to provide an output signal representing the authenticity of said document (12).

8. Apparatus according to claim 7, characterized by analog-to-digital converter means (38) adapted to convert said signals representing light intensity values to digital form for storage in said storage means (42).

9. Apparatus according to claim 7 or claim 8, characterized in that said light dispersing means includes a spectroscope (26).

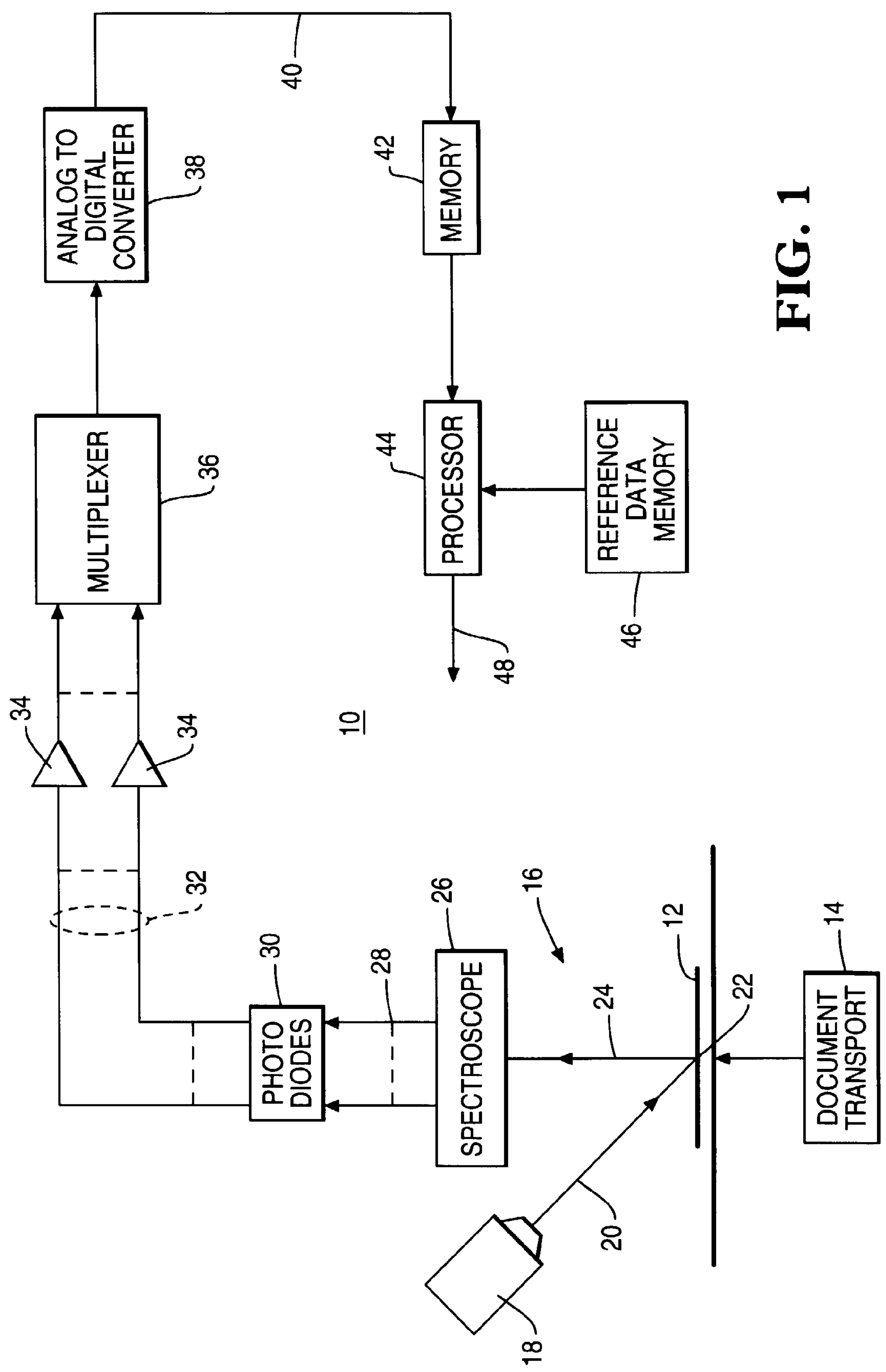

ANALOG TO DIGITAL CONVERTER
38
40
MEMORY
42
MULTIPLEXER
36
PROCESSOR
44
REFERENCE DATA MEMORY
46
48
34
34
10
32
PHOTO DIODES
30
28
SPECTROSCOPE
26
16
24
12
22
14
DOCUMENT TRANSPORT
20
18

FIG. 1

FIG. 2

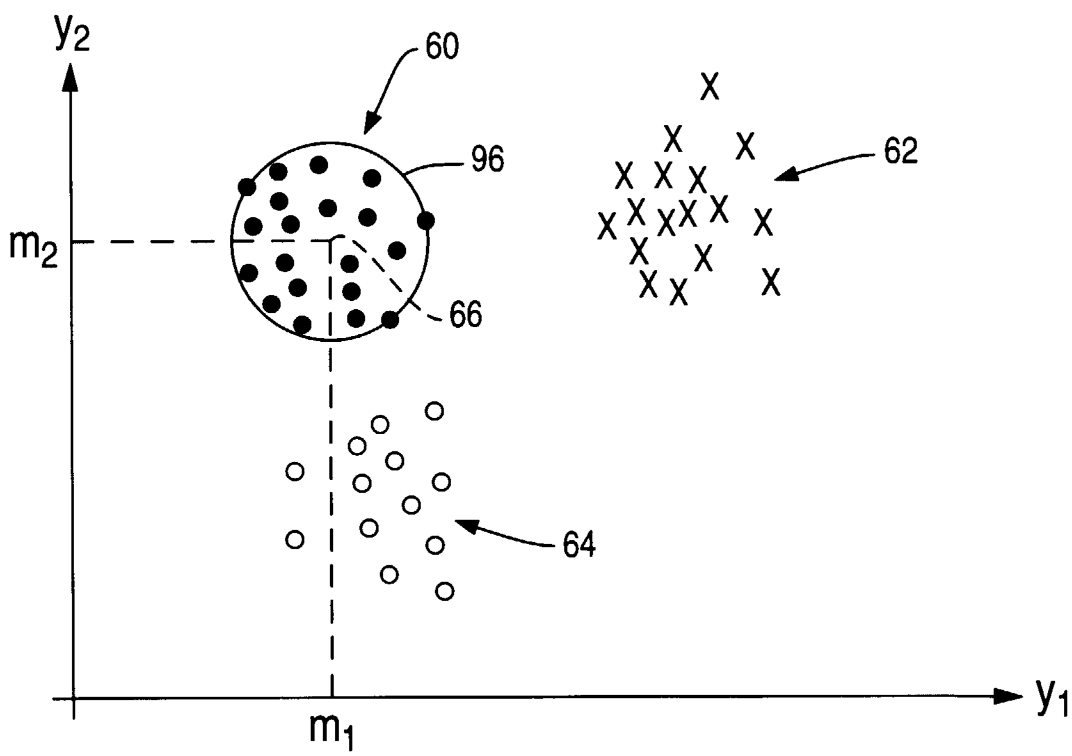
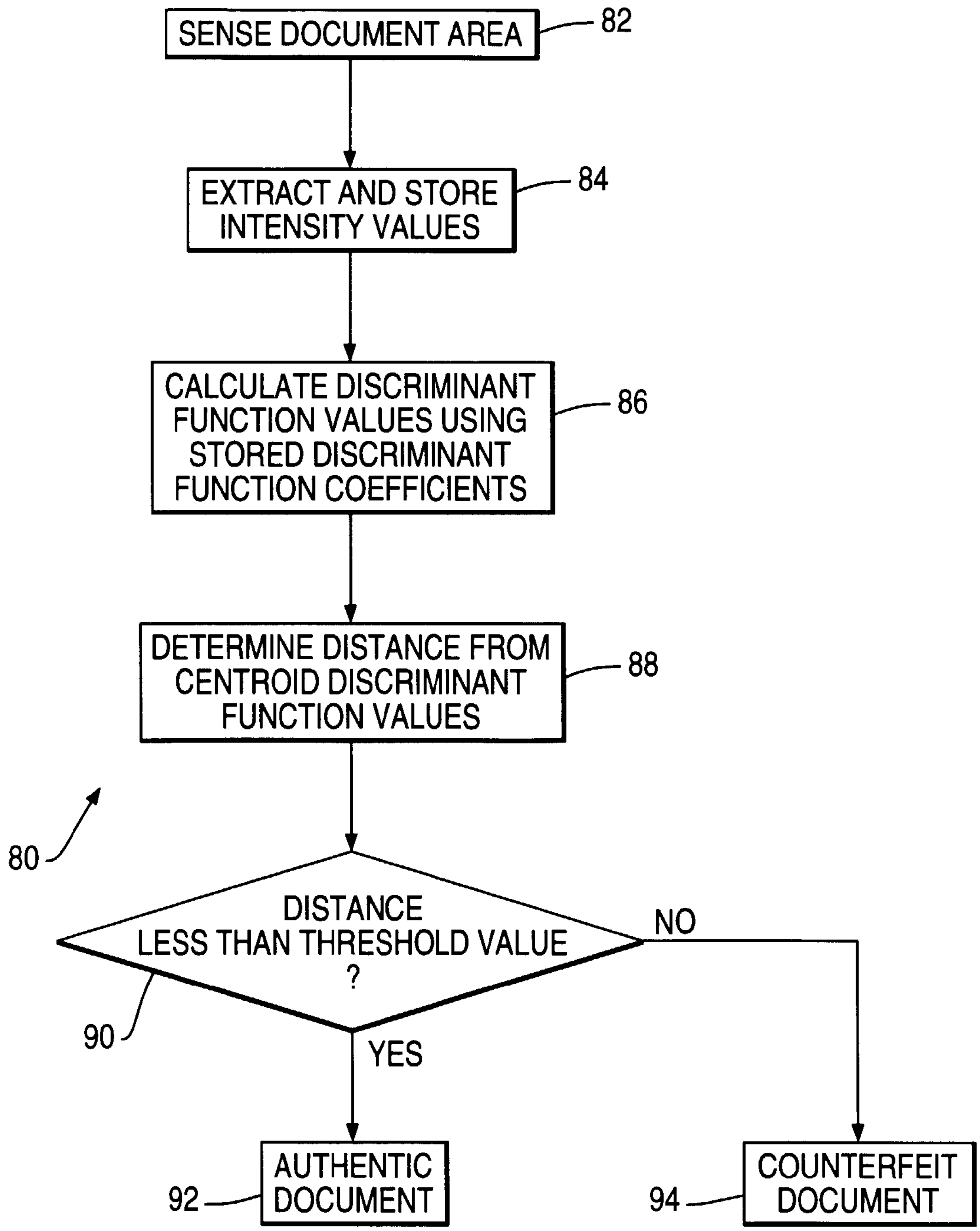


FIG. 3


SENSE DOCUMENT AREA
82
EXTRACT AND STORE INTENSITY VALUES
84
CALCULATE DISCRIMINANT FUNCTION VALUES USING STORED DISCRIMINANT FUNCTION COEFFICIENTS
86
DETERMINE DISTANCE FROM CENTROID DISCRIMINANT FUNCTION VALUES
88
80
DISTANCE LESS THAN THRESHOLD VALUE ?
NO
90
YES
AUTHENTIC DOCUMENT
92
COUNTERFEIT DOCUMENT
94