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(54) BINARY DATA CLASSIFICATION METHOD, BINARY DATA CLASSIFICATION DEVICE, COMPUTER PROGRAM, AND STORAGE MEDIUM

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(57) **ABSTRACT**

An information processing apparatus **100** for realizing a binary data classification method of the present invention includes a CPU for computing a column vector a that has at least a quarter of its components equal to zero, which satisfies diag(y)D″a>0, where a represents a column vector having a coefficient of each term of the set polynomial function as an element, D″ represents a matrix determined on the basis of a combination of the values taken by the respective terms, and y represents a row vector having as an element the value of a class to which binary data in which a value of each element is 1 or −1 should be classified when the binary data is given, and thus classifies the data of an object of classification, which is inputted through a keyboard, in accordance with a set polynomial function.

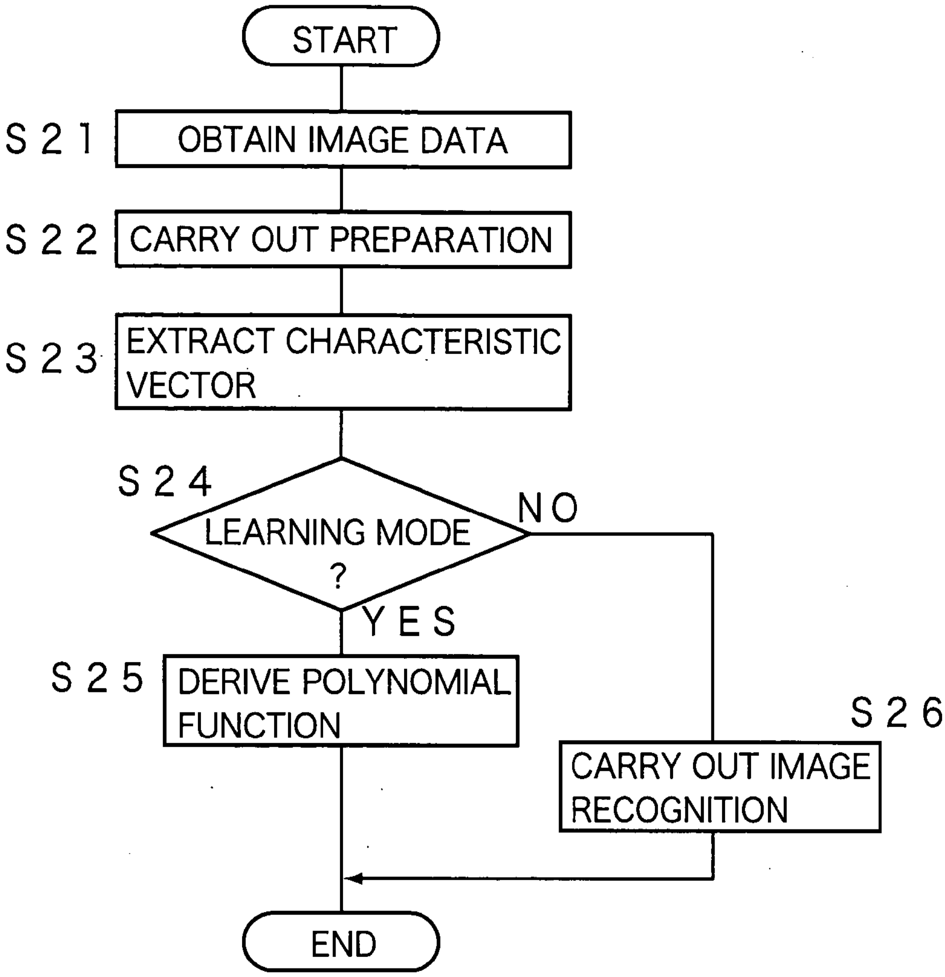


FIG. 1

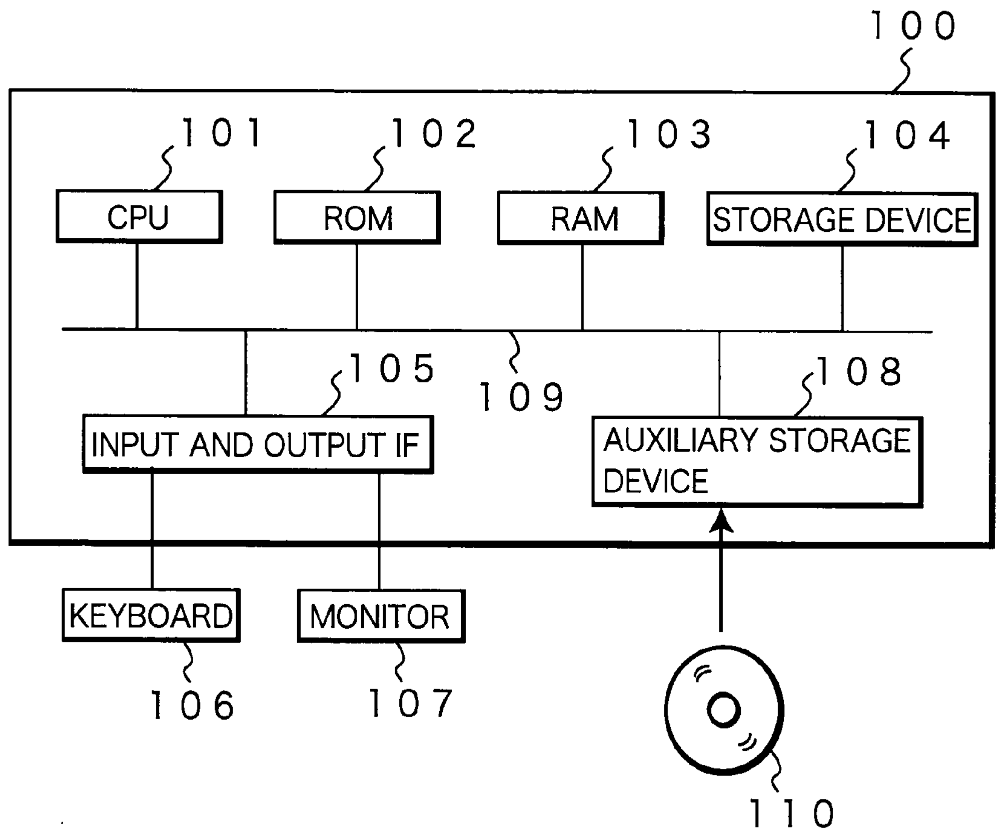

100
101
102
103
104
CPU
ROM
RAM
STORAGE DEVICE
105
109
108
INPUT AND OUTPUT IF
AUXILIARY STORAGE DEVICE
KEYBOARD
MONITOR
106
107
110

FIG. 2

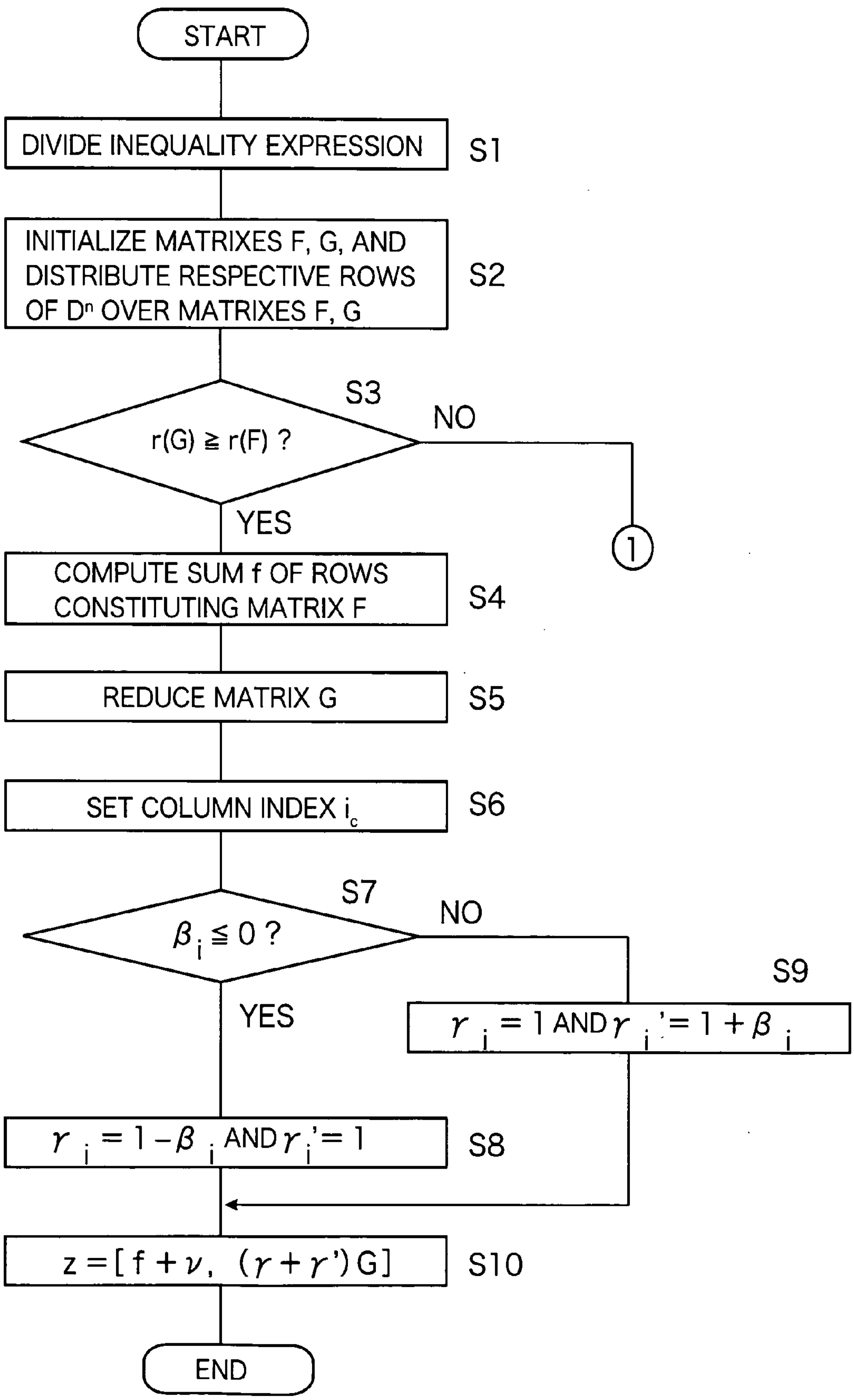

START
DIVIDE INEQUALITY EXPRESSION
S1
INITIALIZE MATRIXES F, G, AND DISTRIBUTE RESPECTIVE ROWS OF D^n OVER MATRIXES F, G
S2
S3
$r(G) \geqq r(F)$?
NO
YES
1
COMPUTE SUM f OF ROWS CONSTITUTING MATRIX F
S4
REDUCE MATRIX G
S5
SET COLUMN INDEX i_c
S6
S7
$\beta_i \leqq 0$?
NO
S9
YES
$\gamma_i = 1$ AND $\gamma_i' = 1 + \beta_i$
$\gamma_i = 1 - \beta_i$ AND $\gamma_i' = 1$
S8
$z = [f + \nu, (\gamma + \gamma')G]$
S10
END

FIG. 3

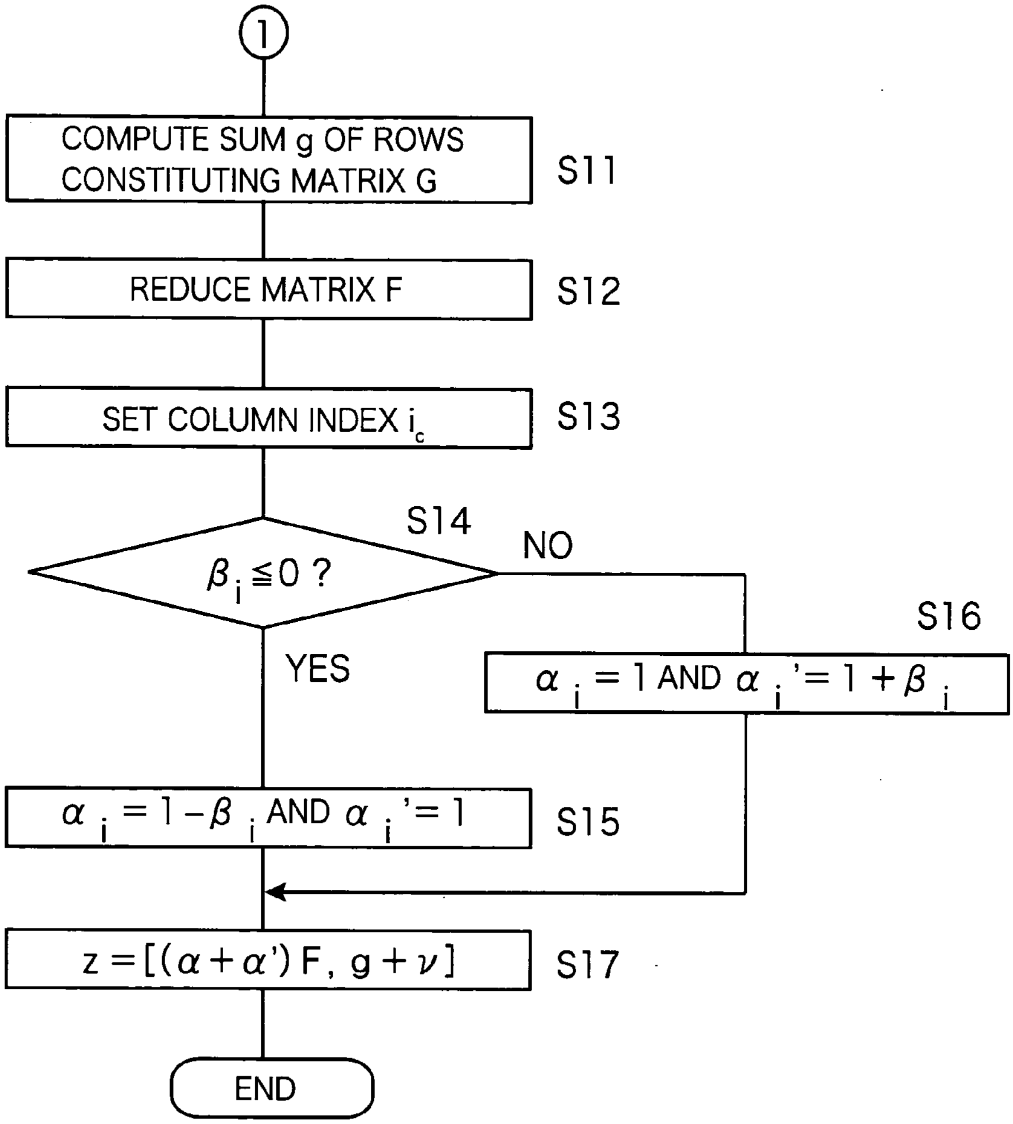

1
COMPUTE SUM g OF ROWS CONSTITUTING MATRIX G
S11
REDUCE MATRIX F
S12
SET COLUMN INDEX i_c
S13
S14
$\beta_i \leqq 0$?
NO
S16
$\alpha_i = 1$ AND $\alpha_i' = 1 + \beta_i$
YES
$\alpha_i = 1 - \beta_i$ AND $\alpha_i' = 1$
S15
$z = [(\alpha + \alpha')F, g + \nu]$
S17
END

FIG. 4

X_0	X_1	X_2	CLASS
1	1	1	−1
−1	1	1	−1
1	−1	1	−1
−1	−1	1	−1
1	1	−1	1
−1	1	−1	1
1	−1	−1	1
−1	−1	−1	1

FIG. 5

1	X_0	X_1	X_1X_0	X_2	X_2X_0	X_2X_1	$X_2X_1X_0$
1	1	1	1	1	1	1	1
1	-1	1	-1	1	-1	1	-1
1	1	-1	-1	1	1	-1	-1
1	-1	-1	1	1	-1	-1	1
1	1	1	1	-1	-1	-1	-1
1	-1	1	-1	-1	1	-1	1
1	1	-1	-1	-1	-1	1	1
1	-1	-1	1	-1	1	1	-1

FIG. 6

d_0	1	1	1	1		1	1	1	1
d_1	1	-1	1	-1		1	-1	1	-1
d_2	1	1	-1	-1		1	1	-1	-1
d_3	1	-1	-1	1		1	-1	-1	1
	1	1	1	1		-1	-1	-1	-1
	1	-1	1	-1		-1	1	-1	1
	1	1	-1	-1		-1	-1	1	1
	1	-1	-1	1		-1	1	1	-1

FIG. 7

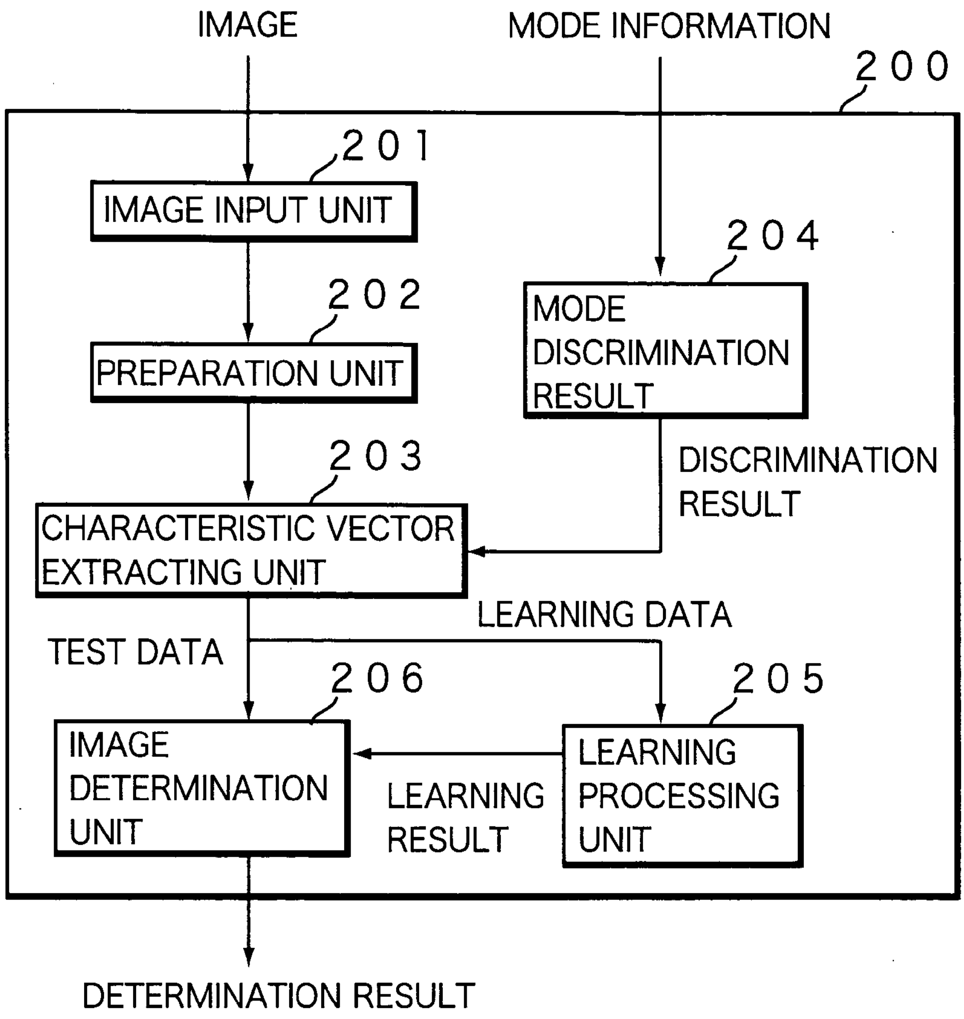


IMAGE
MODE INFORMATION
200
201
IMAGE INPUT UNIT
202
PREPARATION UNIT
204
MODE DISCRIMINATION RESULT
DISCRIMINATION RESULT
203
CHARACTERISTIC VECTOR EXTRACTING UNIT
LEARNING DATA
TEST DATA
206
IMAGE DETERMINATION UNIT
LEARNING RESULT
205
LEARNING PROCESSING UNIT
DETERMINATION RESULT

FIG. 8

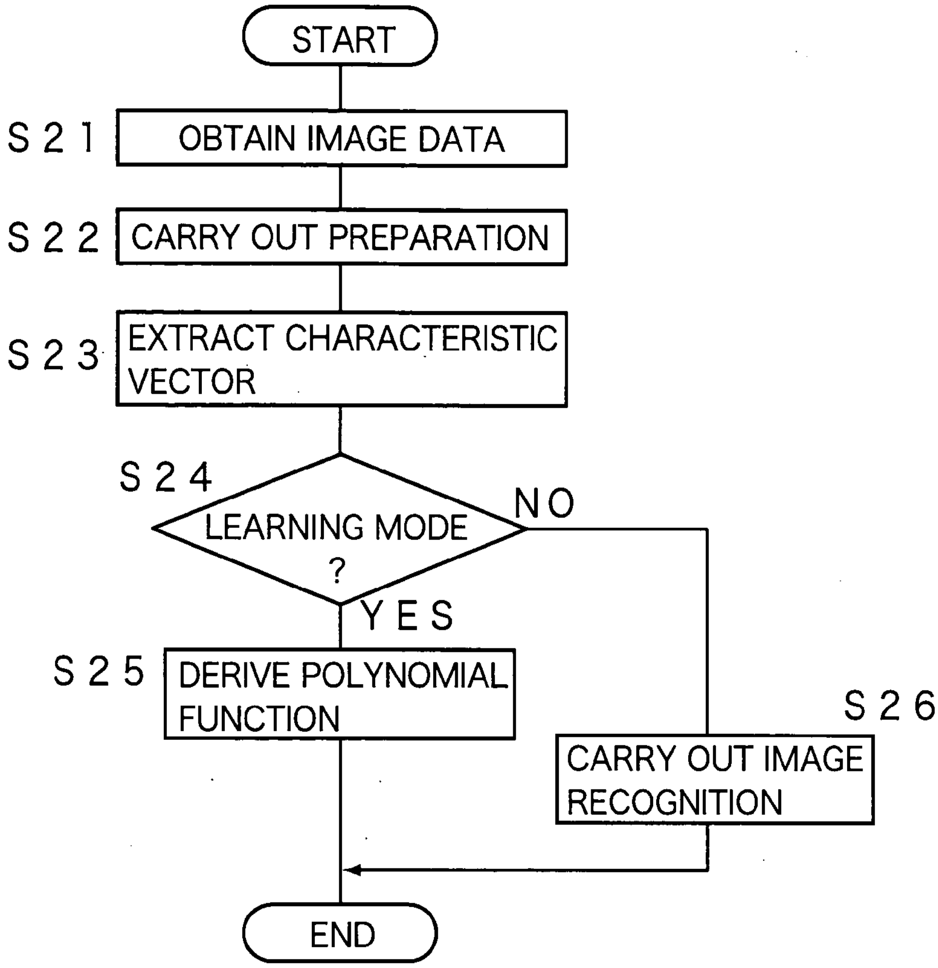

START
S21
OBTAIN IMAGE DATA
S22
CARRY OUT PREPARATION
S23
EXTRACT CHARACTERISTIC VECTOR
S24
LEARNING MODE ?
NO
YES
S25
DERIVE POLYNOMIAL FUNCTION
S26
CARRY OUT IMAGE RECOGNITION
END

FIG. 9

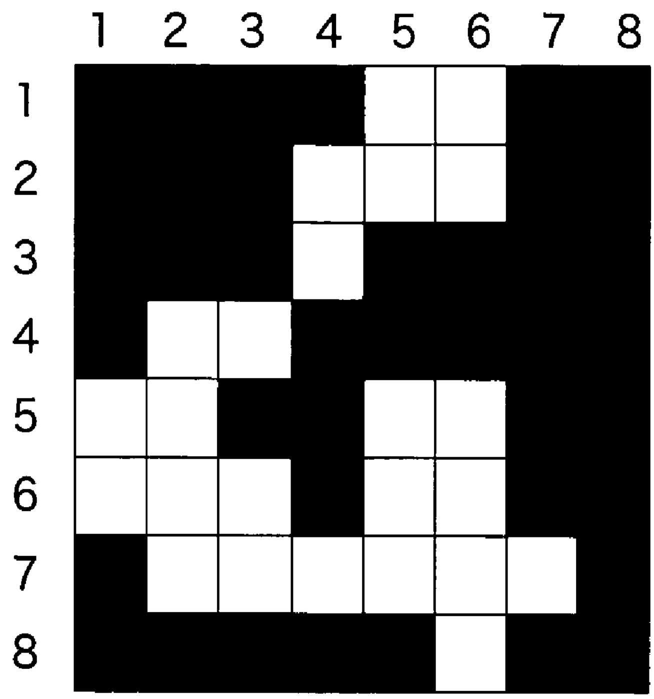


FIG. 10

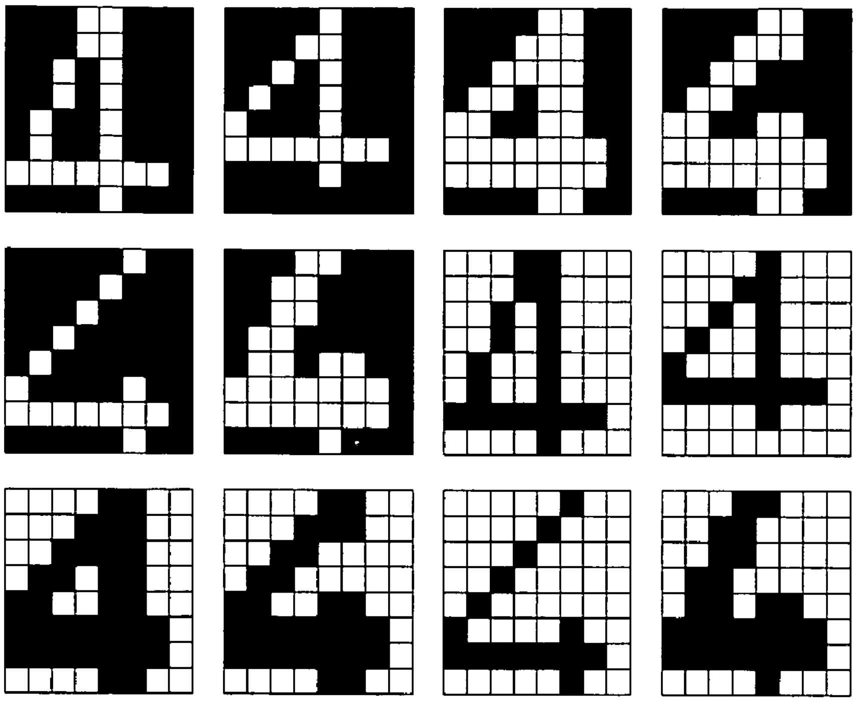
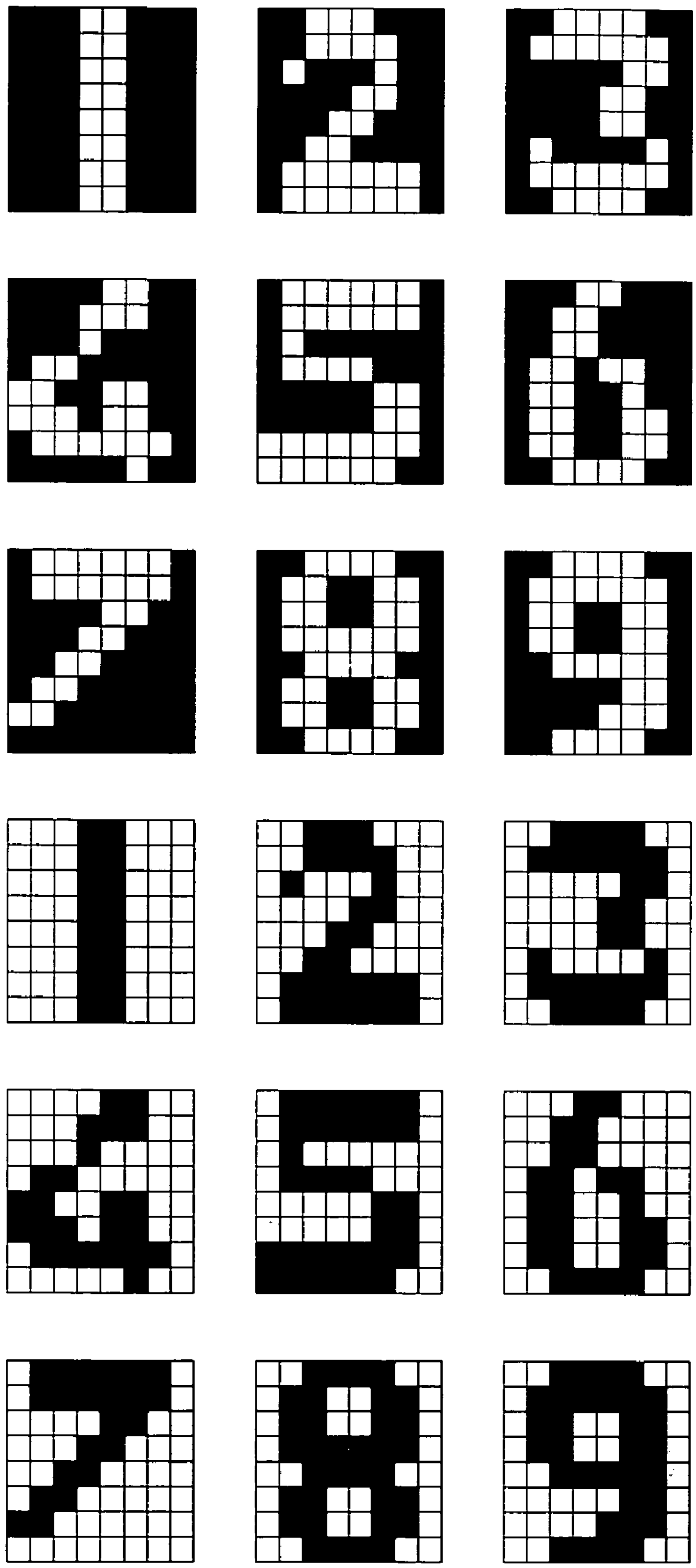


FIG. 11



BINARY DATA CLASSIFICATION METHOD, BINARY DATA CLASSIFICATION DEVICE, COMPUTER PROGRAM, AND STORAGE MEDIUM

TECHNICAL FIELD

[0001] The present invention relates to a data classification method, a data classification device, a computer program, and a storage medium, which can classify binary data into two classes by using a polynomial function having a small number of terms.

BACKGROUND ART

[0002] A data classification method for classifying data in a database having a large quantity of information into a plurality of classes is becoming an essential art for information processing in recent years.

[0003] As for classification of certain data, the data can rarely be classified clearly, so that a method is proposed in which learning is carried out by using data for learning, which has been accurately classified in advance, and classification is carried out on the basis of the learning result. For example, supervised learning to automatically learn how to classify the data from data for learning, of which correct answer has been known in advance, a learning method using a kernel function such as a support vector machine has been known (for example, refer to Patent Document 1).

[0004] [Patent Document 1] Japanese Patent Application Laid-Open No. 2000-293502

DISCLOSURE OF-THE INVENTION

Problems to be Solved by the Invention

[0005] As a kernel function, one using an inner product is a main stream, however, it has been known that it takes a much longer time for classification as compared to other conventional methods in the case of using an inner product. This is because so many calculations of inner product in the range of several thousands to several hundred thousands are necessary for classification of one data.

[0006] On the other hand, in a two-class classification problem to classify the given data into two classes, a polynomial function is used in many cases. By setting a threshold in advance and assigning the polynomial function with the given data, a value of this polynomial function is obtained, and by checking a magnitude relation with the threshold, it is capable of classifying the data into two classes.

[0007] However, in a field of a neural network or the like, there is such a problem that the number of monomials constituting polynomial functions to be set is significantly increased and a high-capacity memory and a high-speed computing device are needed.

[0008] The present invention has been made taking the foregoing problems into consideration and an object thereof is to provide a data classification method, a data classification device, a computer program, and a storage medium, which can provide an upper limit to the number of monomials' necessary for solving a two-class classification problem by setting a polynomial function having the number of terms fewer than $3\times2^{n-2}$ in order to classify the binary data into two classes.

Means for Solving the Problems

[0009] A first aspect of the present invention provides a data classification method comprising: setting a function to define binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; computing the value of the function by substituting the set function with respective elements of the given binary data; and carrying out classification of the binary data on the basis of the value of the computed function; wherein a polynomial function, the number of whose monomials for classifying the binary data into two classes is less than $3\times2^{n-2}$, is set.

[0010] A second aspect of present invention provides a data classification method, wherein binary data, each element of which has a value of 1 or 1, is used as data to be classified, and a row vector a that satisfies diag(D^n)a>0 is computed, where the column vector comprising the coefficient of each monomial of said polynomial function to be set is a, the matrix determined on the basis of the combination of values said respective monomials can take is D^n, and when binary data is given, the row vector comprising the values of the classes into which said binary data is classified is y.

[0011] A third aspect of present invention provides a data classification device for setting a function to define binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; computing the value of the function by substituting the set function with respective elements of the given binary data; and carrying out classification of the binary data on the basis of the value of the computed function; comprising means for setting a polynomial function, the number of whose monomials for classifying said binary data into two classes is less than $3\times2^{n-2}$.

[0012] A fourth aspect of present invention provides a data classification device, comprising means for accepting binary data in which a value of each element is 1 or −1 and means for computing a row vector a that satisfies diag(D^n)a>0, where the column vector comprising the coefficient of each monomial of said polynomial function to be set is a, the matrix determined on the basis of the combination of values said respective monomials can take is D^n, and when binary data is given, the row vector comprising the values of the classes into which said binary data is classified is y.

[0013] A fifth aspect of the present invention provides a computer program, which allows a computer to set a function to define binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; and to compute the value of the function by substituting the set function with respective elements of the given binary data; and to carry out classification of the binary data on the basis of the value of the computed function; comprising a step of allowing the computer to set a polynomial function, the number of whose monomials for classifying the binary data into two classes is less than $3\times2^{n-2}$.

[0014] A sixth aspect of the present invention provides a computer program, comprising a step of allowing the computer to compute a row vector a that satisfies diag(D^n)a>0, where the column vector comprising the coefficient of each monomial of said polynomial function to be set is a, the matrix determined on the basis of the combination of values said respective monomials can take is D^n, and when binary data is given, the row vector comprising the values of the classes into which said binary data is classified is y.

[0015] A seventh aspect of the present invention provides a computer readable storage medium storing a computer program which allows a computer to set a function to define binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; and to compute the value of the function by substituting the set function with the respective elements of the given binary data; and to carry out classification of the binary data on the basis of the value of the computed function; wherein the storage medium stores a computer program, comprising a step of allowing the computer to set a polynomial function, the number of whose monomials for classifying the binary data into two classes is less than $3\times2^{n-2}$.

[0016] A eighth aspect of the present invention provides a computer readable storage medium storing a computer program, wherein the storage medium stores a computer program, comprising a step of allowing the computer to compute a row vector a that satisfies diag(D^n)a>0, where the column vector comprising the coefficient of each monomial of said polynomial function to be set is a, the matrix determined on the basis of the combination of values said respective monomials can take is D^n, and when binary data is given, the row vector comprising the values of the classes into which said binary data is classified is y.

[0017] In the first, third, fifth and seventh inventions, the number of monomials necessary to solve the two-class classification problem is decreased because a function for use in classifying the binary data into two classes is set to be a polynomial function having terms in a number fewer than $3\times2^{n-2}$.

[0018] In the second, fourth, sixth and eighth inventions, respective coefficients of a polynomial function to be set are represented by a column vector $a=[a_0, a_1, \ldots, a_m]^T$ ($m=2^n-1$), and under the condition of diag(y)D^na>0, the column vector a is obtained, so that at least ¼ of elements of the column vector a becomes zero.

EFFECTS OF THE INVENTION

[0019] According to the first, third, fifth and seventh inventions, as a criterion for classifying the binary data into two classes, a polynomial function is used, and further, the number of terms is set to be fewer than $3\times2^{n-2}$. Generally, by using a polynomial function made of 3×2^n pieces of monomials, any type of two-class classification problem can be solved. However, in the present invention, a polynomial function can be set by using monomials fewer than $3\times2^{n-2}$. Therefore, even in the case of solving a large problem, it is possible to reduce a memory to be used and improve a computing speed.

[0020] According to the second, fourth, sixth and eighth inventions, respective coefficients of a polynomial function to be set are represented by a column vector $a=[a_0, a_1, \ldots, a_m]^T$, and the column vector a is obtained under the condition of diag(y)D^na>0, so that at least ¼ of elements of the column vector a becomes zero. Accordingly, the number of terms of the polynomial function can be decreased to be fewer than 2^{n-2}, and even in the case of solving a large problem, it is possible to reduce a memory to be used and improve a computing speed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. **1** is a block diagram showing an internal constitution of a data classification device according to the present invention.

[0022] FIG. **2** is a flow chart for explaining a procedure of a processing to be carried out by an information processing apparatus for obtaining a polynomial function.

[0023] FIG. **3** is a flow chart for explaining a procedure of a processing to be carried out by an information processing apparatus for obtaining a polynomial function.

[0024] FIG. **4** is a diagram for showing an example of a class classification problem.

[0025] FIG. **5** is a diagram showing elements of a matrix D^3.

[0026] FIG. **6** is a diagram showing a divided matrix D^3.

[0027] FIG. **7** is a block diagram showing an internal constitution of an image recognition apparatus according to the present invention.

[0028] FIG. **8** is a flow chart for explaining a procedure of a processing to be carried out by the image recognition apparatus.

[0029] FIG. **9** is a pattern diagram showing an example of image data to be obtained by the image recognition apparatus.

[0030] FIG. **10** is a pattern diagram showing an example of an image to be prepared as learning data.

[0031] FIG. **11** is a pattern diagram showing test data.

EXPLANATION OF THE REFERENCE NUMERALS

[0032] **100**: information processing apparatus
[0033] **101**: CPU
[0034] **102**: ROM
[0035] **103**: RAM
[0036] **104**: storing device
[0037] **105**: input and output-IF
[0038] **106**: keyboard
[0039] **107**: monitor
[0040] **108**: auxiliary storage device
[0041] **110**: storage medium

BEST MODE FOR CARRYING OUT THE INVENTION

[0042] Hereinafter, the present invention will be specifically described with reference to the drawings showing the embodiment thereof.

First Embodiment

[0043] FIG. **1** is a block diagram showing an internal constitution of a data classification device according to the present invention. The data classification device according to the present invention is realized by an information processing apparatus **100** such as a personal computer and a work station. The information processing apparatus **100** is provided with a CPU **101** as a computing device, and hardware such as a ROM **102**, a RAM **103**, a storage device **104**, an input and output IF **105**, and an auxiliary storage device **108** are connected to this CPU **101** via a bus **109**.

[0044] In the ROM **102**, a control program for controlling the operation of various hardware connected to the bus **109** is stored. The CPU **101** loads and executes this control program on the RAM **103** to control the operation of the entire hardware.

[0045] The storage device **104** is provided with a hard disc drive to store a computer program for realizing the data classification method of the present invention and the data needed for executing this computer program or the like.

[0046] To the input and output IF **105**, a keyboard **106** as the input device and a monitor **107** as an output device are connected. The information processing apparatus **100** accepts the data as a classification object and an activation start instruction of the above-described computer program or the like through the keyboard **106**. In addition, the information processing apparatus **100** displays a parameter inputted through the keyboard **106**, and a classification result, which is a computation result of the above-described computer program, or the like on the monitor **107**.

[0047] Further, the above-described computer program is not necessarily preinstalled in the storage device **104** and may be provided by a storage medium **110** such as an FD, a CD-ROM, and a DVD. Therefore, the information processing apparatus **100** is provided with the auxiliary storage device **108** such as an FD drive, a CD-ROM drive, and a DVD drive for reading a computer program from the storage medium **110**, in which the computer program is stored. The computer program read by the auxiliary storage device **108** is stored in the storage device **104**. The CPU **101** allows the information processing apparatus **100** to operate as a data classification device according to the present invention by loading and executing the above-described computer program from the storage device **104** on the RAM **103** as needed.

[0048] According to the present embodiment, through the computing processing by means of the information processing apparatus **100**, a two-class classification problem to be described below will be solved. The two-class classification problem is given by $C=(S^+, S^-)$. Here, S^+ and S^- satisfy $S^+\subset\{-1, 1\}^n$ and $S^-\subset\{-1, 1\}^n$, and they represent different classes from each other. An expression of $f(x):\{-1, 1\}^n\rightarrow R$ (R is a real number) becomes a solution for C, in which $f(x)>0$ is established to any x that satisfies $x\in S^+$, and $f(x)<0$ is established that satisfies x to satisfy $x\in S^-$.

[0049] According to the present embodiment, as a solution of a two-class classification problem, a polynomial function p $(x_0, x_1, \ldots, x_{n-1})$ is obtained. The polynomial function p $(x_0, x_1, \ldots, x_{n-1})$ will be given by the following expression.

$$p(x_0, x_1, \ldots, x_{n-1}) = \sum_{i=0}^{2^n-1} a_i \prod_{k\in S_i} x_k \quad \text{[Expression 1]}$$

[0050] Here, $S_i\subset\{0, 1, \ldots, n-1\}$ is established, and $x_i^2=1$ is established to all i. Each term of a polynomial function p $(x_0, x_1, \ldots, x_{n-1})$ excluding a coefficient a_i is referred to as a monomial.

[0051] Next, indexing of a monomial with a combination of terms is defined. A function K(m) will be defined by the following expression.

$$K(m) = K\left(\prod_{k\in S_i} x_k\right) = 1 + \sum_{k\in S_i} 2^k \quad \text{[Expression 2]}$$

[0052] In this case, the function K(m) expresses one-to-one mapping between a set of monomials and $\{1, 2, \ldots, 2^n\}$. Therefore, indexing to a monomial is expressed by the following expression:

$$m_j = \prod_{k\in S_i} x_k \Leftrightarrow j = K\left(\prod_{k\in S_i} x_k\right) \quad \text{[Expression 3]}$$

[0053] In addition, a coefficient m_j is identified as a coefficient a_j. Through to this indexing, the polynomial function p is expressed by the following expression with a vector notation.

$$p(x_0, \ldots, x_{n-1}) \equiv (a_0, \ldots, a_{2^n-1}) \quad \text{[Expression 4]}$$

[0054] In this case, the computing of the polynomial function p is internally given by the following expression.

$$(a_0, \ldots, a_{2^n-1})m_0, \ldots, m_{2^n-1})^T|_{(x_0, \ldots x_{n-1})} \quad \text{[Expression 5]}$$

[0055] Next, the polynomial function p is formulated by using a matrix.

$$p(x_0,x_1, \ldots, x_{n-1})=a_0+a_1x_0+a_2x_1+a_3x_1x_0+ \ldots +a_{2n-1}x_{n-1}x_n \ldots x_0 \quad \text{[Expression 6]}$$

$$d_i=(m_0, \ldots, m_{2^{-1}})|_{i=\chi(x_0, \ldots xn-1)}$$

$$a=[a_0,a_1, \ldots, a_{2^n-1}]^T \quad \text{[Expression 6]}$$

[0056] In this case, $D^n{}_a$ expresses an influence of the polynomial function p on $\{-1, 1\}^n$. Here, D^n is a matrix of $2^n\times2^n$ and this is given by the following expression:

$$D^n = \begin{bmatrix} d_0 \\ \vdots \\ d_{2^n-1} \end{bmatrix} \quad \text{[Expression 7]}$$

[0057] Here, D^n is referred to as a substitution matrix of an order n, and $D^n{}_a$ is a matrix expression of the polynomial function p. For example, the substitution matrix of the second order can be expressed as follows:

$$p(x_0, x_1) = a_0 + a_1x_0 + a_2x_1 + a_3x_1x_0 \text{ on } \{-1, 1\}^2 \quad \text{[Expression 8]}$$

$$p(\{-1, 1\}^2) \equiv \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} p(+1, +1) \\ p(-1, +1) \\ p(+1, -1) \\ p(-1, -1) \end{bmatrix}$$

[0058] In a two-class classification problem $C=(S^+, S\_)$, the column of the matrix D^n is divided into $D+^n$ and $D-^n$ so as to satisfy a condition of $D+n_a>0$, $D-^n{}_a>0$. Here, $a=[a_0, a_1, \ldots, a_n]^T\in R^n$ is a coefficient of the polynomial function p.

$$Y = \begin{bmatrix} y_1 & & \\ & \ddots & \\ & & y_{2^n} \end{bmatrix} \text{ where, } y_i = \begin{cases} -1 & \text{if } i \in \chi(S^-) \\ +1 & \text{if } i \in \chi(S^+) \end{cases} \quad \text{[Expression 9]}$$

[0059] When the expression 9 is defined, the two-class classification problem C is equal to obtaining a vector $a=[a_0, a_1, \ldots, a_n]^T\in R^n$ so that $YD^na>0$ is established.

[0060] Next, a specific algorithm will be described. Each of FIG. **2** and FIG. **3** is a flow chart for explaining a procedure of a processing to be carried out by the information processing apparatus **100** for obtaining a polynomial function. As described above, any two-class classification problem can be expressed by $\mathrm{diag}(y)D^nz>0$. Here, $y\in\{-1, 1\}^n$ is established, and a vector z is a column vector to give a coefficient of a monomial constituting a polynomial function to be obtained.

[0061] First, the CPU **101** of the information processing apparatus **100** divides the above-described inequality expression into two parts (step S1). In other words, $\mathrm{diag}(y)D^nz>0$ is expressed as follows:

$$\mathrm{diag}\left(\begin{bmatrix} y^u \\ y^d \end{bmatrix}\right)\begin{bmatrix} d_0 & d_0 \\ \vdots & \vdots \\ d_{2^n-1} & d_{2^n-1} \\ d_0 & d_0 \\ \vdots & \vdots \\ d_{2^n-1} & d_{2^n-1} \end{bmatrix}\begin{bmatrix} x \\ t \end{bmatrix} > 0 \quad \text{[Expression 10]}$$

[0062] Next, the CPU **101** initializes matrixes F and G, and respective rows of $d_0, d_1, \ldots, d_m$ ($m=2^n-1$) are distributed as follows (step S**2**). In other words, in the case of $(y_{iu}, y_{id})=(+1, +1)$, d_i is added to the matrix F, and in the case of $(y_{iu}, y_{id})=(-1, -1)$, $-d_i$ is added to the matrix F. In addition, in the case of $(y_{iu}, y_{id})=(+1, -1)$, d_i is added to the matrix G, and in the case of $(y_{iu}, y_{id})=(-1, +1)$, $-d_i$ is added to the matrix G.

[0063] Next, the CPU **101** compares the number of rows constituting the matrix F and the matrix G to determine if the number of rows r(G) constituting the matrix G is not less than r(G), which is the number of rows constituting the matrix F, or not (step S**3**).

[0064] In the case that the number of rows constituting each of the matrix F and the matrix G satisfies $r(G) \geqq r(F)$ (S**3**: YES), the following processing will be carried out. First, the CPU **101** obtains a sum f of the rows constituting the matrix F (step S4). In addition, the row reduced Echelon form of G (G') to be obtained by reducing the matrix G is obtained (step S**5**). Consequently, a first nonzero element that appears in the ith row of the matrix G' is determined to be a column index i_c (step S6). Further, v and β are given by the following expression:

$$v = \sum_{i=1 \ldots r(G)} -f_{i_c} G'_i \quad \text{[Expression 11]}$$

$$\beta = 2^{-(n-1)} v G^T$$

[0065] Then, the CPU **101** checks each element β_i of β, and determines if each element β_i is not more than 0 or not (step S7). If the CPU**101** determines that the value of β_i is not more than 0 (S7: YES), the CPU **101** calculates $\gamma_i=1-\beta_i$ and may set γ_i' at 1 (step S**8**). In addition, when the CPU**101** determines that the value of β_i is larger than 0 (S7: NO), the CPU **101** sets γ_i at 1 and calculates $\gamma_i'=1+\beta_i$ (step S9).

[0066] In this case, the CPU **101** gives a vector z expressing respective coefficients of the polynomial function by the following expression: (step S**10**)

$$z=[f+v,(\gamma+\gamma')]G \quad \text{[Expression 12]}$$

[0067] Here, the CPU **101** ends the computation by the present routine.

[0068] On the other hand, in the case that the number of rows constituting each of the matrix F and the matrix G satisfies r(G)<r(F) (S**3**: NO), the following processing will be carried out. First, the CPU **101** obtains a sum g of the rows to constitute the matrix G (step S**11**). In addition, the row reduced Echelon form of F (F') to be obtained by reducing the matrix F is obtained (step S**12**). Consequently, a first nonzero element that appears in the ith row of the matrix F' is determined to be a column index i_c (step S**13**). Further, v and β are given by the following expression:

$$v = \sum_{i=1 \ldots r(F)} -g_{i_c} F'_i \quad \text{[Expression 13]}$$

$$\beta = 2^{-(n-1)} F^T$$

[0069] Then, the CPU **101** checks each element β_i of β, and determines if each element β_i is not more than 0 or not (step S**14**). If the CPU**101** determines that the value of β_i is not more than 0 (S**14**: YES), the CPU **101** calculates $\alpha_i=1-\beta_i$ and sets α_i' at 1 (step S**15**). In addition, when the CPU**101** determines that the value of β_i is larger than 0 (S**14**: NO), the CPU **101** sets α_i at 1 and calculates $\alpha_i'=1+\beta_i$ (step S**16**).

[0070] In this case, the CPU **101** gives a vector z expressing respective coefficients of the polynomial function by the following expression: (step S**17**)

$$z=[(\alpha+\alpha')F,g+v] \quad \text{[Expression 14]}$$

[0071] Here, the CPU **101** ends the computation by the present routine.

[0072] A computation result of this algorithm, namely, z satisfies the above-described inequality expression diag(y) $D^n z>0$ and gives a solution to the two-class classification problem. An important and new property of this algorithm is that $2^n/4$ among the elements to constituting the vector z, which is obtained as a solution, is zero. In other words, the number of terms of the obtained polynomial function (the monomial) becomes the number fewer than $3\times2^{n-2}$ to any two-class classification problem to be classified into $\{-1, 1\}$. As a result, in the case that data as a classification object is given, a computation resource such as a memory capacity can be controlled to be lower, and a high speed classification become possible.

[0073] Next, an application example will be described. FIG. **4** is a diagram for showing an example of a class classification problem. In FIG. **4**, a value of a class is defined, to which data should belong when elements X_0, X_1, X_2 is given. Since there are three elements, according to the present invention, a polynomial function constituted by a monomial having terms fewer than six ($=3\times2^{n-2}=3\times2^1$) is obtained.

[0074] In the case of applying the above-described algorithm, the two-class classification problem is equal to obtaining of z to satisfy diag(y)D^3z>0. Here, y=[−1, −1, 1, 1, 1, −1, −1, −1] is established, and D^3 is defined as a matrix having the elements shown in the diagram of FIG. **5**.

[0075] Through the processing of step S**1**, a vector y is divided into y_u=[−1, −1, 1, 1] and y_d=[1, −1, −1, −1], and a matrix D^n is divided like the diagram shown in FIG. **6**.

[0076] Through the processing of step S**2**, the matrixes F and G are initialized to distribute respective rows of the matrix D^n. In other words, since $(y_{0u}, y_{0d})=(-1, +1)$ is established, $-d_0$ is added to the matrix G. In the same way, since $(y_{1u}, y_{1d})=(-1, -1)$ is established, $-d_1$ is added to the matrix F, since $(y_{2u}, y_{2d})=(+1, -1)$ is established, d_2 is added to the matrix G, and since $(y_{3u}, y_{3d})=(+1, -1)$ is established, d_3 is added to the matrix F. As a result, the number of rows of the matrix F, r(F) is 1, and the number of rows of the matrix G, r(G) is 3.

[0077] In order to satisfy the condition of $r(G) \geqq r(F)$, the CPU carries out the processing of step S**4** to obtain a sum f of the rows constituting the matrix F. As a result, f=(−1, 1, −1, 1) is obtained. In addition, through the processing of step S**12**, reducing the matrix G, the row reduced Echelon form of G (G') is obtained. The matrix G' is represented by the following expression.

$$G' = \begin{pmatrix} 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 1 \end{pmatrix}$$ [Expression 15]

[0078] A column index is determined to be $1_c=1$, $2_c=2$, $3_c=3$ from this matrix G'. In this case, v and β are calculated as follows:

$$v=-f_1G'_1-f_2G'_2-f_3G'_3=(1,-1,1,3)$$

$$\beta=2^{-2}I(1,-1,1,3)G^T=(-1,-1,1)$$ [Expression 16]

[0079] Next, checking positive and negative of respective elements of β, γ and γ' are obtained. Then, γ and γ' are obtained, respectively, as follows: γ=(2, 2, 1), and γ'=(1, 1, 2). In this case, since z=[f+v, (γ+γ') G] is established, respective elements of z are obtained, so that z=(0, 0, 0, 4, 3, −3, −9, −3) is established.

[0080] In this way, a solution of the two-class classification problem is obtained as follows:

$$p(x_0,x_1,x_2)=-3x_2x_1x_0-9x_2x_1-3x_2x_0+3x_2+4x_1x_0$$ [Expression 17]

[0081] In the case of substituting the above expression with the values of x_0, x_1, and x_2, it is clear that the definition shown in FIG. 4 is satisfied. In addition, the number of monomials to constitute the polynomial function p (x_0, x_1, x_2) is 5, and it is clear that the number of monomials is fewer than $3\times2^{n-2}$.

Second Embodiment

[0082] By using the data classification device, which has been explained in the first embodiment, it is possible to build an image recognition apparatus to realize character recognition and pattern recognition or the like. According to the present embodiment, an image recognition apparatus to recognize a digital number made of 8×8 pixels will be described.

[0083] FIG. **7** is a block diagram showing an internal constitution of an image recognition apparatus according to the present embodiment. An image recognition apparatus **200** is provided with an image input unit **201**, a preparation unit **202**, a characteristic vector extracting unit **203**, a mode discrimination unit **204**, a learning processing unit **205**, and an image determination unit **206**.

[0084] The image input unit **201** is an input device such as a scanner, which optically reads an image such as a character and a pattern, and the image data obtained by this image input unit **201** is outputted to the preparation unit **201**.

[0085] The preparation unit **202** is a processing unit to carry out the preparation of the image data, which is received from the image input unit **201**. Specifically, after smoothing the image data and removing a noise from the image, by binarizing this image data with a predetermined threshold, a binary image is generated. Further, in the case that the inputted image data is a monochrome image, the binarization processing can be omitted.

[0086] The characteristic vector extracting unit **203** extracts a vector expressing a characteristic of an image (hereinafter, referred to as a characteristic vector). As a method of extracting a characteristic vector, any extraction method may be utilized, whereby a vector having predetermined number of elements can be outputted while a value of each element is 1 or −1.

[0087] The image recognition apparatus **200** has a learning mode for learning the image, which is an object of recognition, and a determination mode for realizing the image recognition with respect to the inputted image, and the image recognition apparatus **200** accepts the information (mode information) for discriminating a mode from the outside. The mode discrimination unit **204** sends a determination result to the characteristic vector extracting unit **203** according to the mode information, which is accepted from the outside.

[0088] When the determination result of the mode discrimination unit **204** indicates the learning mode, the characteristic vector extracting unit **203** outputs the extracted characteristic vector as learning data to the learning processing unit **205**, and when the determination result of the mode discrimination unit **204** indicates the determination mode, the characteristic vector extracting unit **203** outputs the extracted characteristic vector as test data to the learning processing unit **205**.

[0089] The learning processing unit **205** decides a polynomial function, which provides a solution of a two-class classification problem, by using the inputted characteristic vector. In other words, by regarding the inputted characteristic vector as a vector y, which is described in the first embodiment, and carrying out computation using the above-described method, respective coefficients of a polynomial function are obtained. The learning processing unit **205** notifies the image determination unit **206** of the decided polynomial function as a learning result.

[0090] On the other hand, the image determination unit **206** carries out the image recognition by substituting the polynomial function, which is decided by the learning processing unit **205**, with the characteristic vector, which is extracted from the newly inputted image. In the case that the inputted image is determined to be an image of an object of recognition, the polynomial function outputs "1", and in the case that the inputted image is determined to be different from an image of an object of recognition, the polynomial function may output "−1".

[0091] Hereinafter, the procedure of the processing to be carried out by the image recognition apparatus **200** will be described. FIG. **8** is a flow chart for explaining a procedure of a processing to be carried out by the image recognition apparatus **200**. At first, the image recognition apparatus **200** may obtain the image data through the image input unit **201** (step S**21**) to carry out the preparation (step S**22**). FIG. **9** is a pattern diagram showing an example of image data to be obtained by the image recognition apparatus **200**. This example is a two-dimensional image showing a number "4", which is constituted by 8 pixels×8 pixels, and each pixel is binarized.

[0092] Next, the characteristic vector extracting unit **203** of the image recognition apparatus—200 extracts the characteristic vector (step S**23**). As an extraction method of the characteristic vector, an existing method can be used. According to the present embodiment, the extraction method for outputting the characteristic vector of 10 bits having 1 or −1 as an element to the above-described image made of 8 pixels×8 pixels is utilized.

[0093] Then, the characteristic vector extracting unit **203** may determine if the mode is a learning mode or not on the basis of the determination result of the mode discrimination unit **204** (step S**24**). In the case the mode is the learning mode (S**24**: YES), the polynomial function is derived (step S**25**). For deriving the polynomial function, by preparing a plurality of images as a recognition object, it is possible to improve an accuracy of recognition. For example, in the case that the image of the number "4" is defined to be a recognition object, images as shown by a pattern diagram of FIG. **10** are prepared as the learning data. By applying the method according to the first embodiment, it is possible to decide the polynomial function which can give a solution of the two-class classification problem.

[0094] In the case that the characteristic vector extracting unit **203** determines that the mode is not a learning mode in step **24** (S**24**: NO), the image recognition apparatus **200** carries out image recognition by the image determination unit **206** (step S**26**). However, it is necessary to decide the polynomial function of step S**25** prior to the image recognition. The image recognition is carried out by substituting the polynomial function decided by the learning processing unit **205** with the characteristic vector extracted from the newly inputted image. For example, when the test data shown in the pattern diagram of FIG. **11** is inputted, it is possible to recognize the second image and the fifth image from the top of the first column from the left can be recognized as the number "4".

[0095] In the case of inputting the learning data shown in FIG. **10** and obtaining the polynomial function, according to a conventional method, 704 pieces of monomials are needed, whereas, when the method according to the present invention is applied, the solution can be described by 356 pieces of monomials. In other words, it has become clear that it is possible to decrease the number of monomials to about 50% or less, about half of the memory capacity can be saved, and classification can be realized at a computing speed approximately two times faster than the normal.

[0096] Further, the present embodiment is described as an apparatus for recognizing the image of the number "4", however, it is obvious that the apparatus recognizes other numbers, other characters, and arbitrary patterns.

1. A data classification method comprising: setting a function to define binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; computing the value of the function by substituting the set function with respective elements of the given binary data; and carrying out classification of the binary data on the basis of the value of the computed function;

wherein, a value of each element is 1 or −1; the binary data inputted within an information processing apparatus is defined to be an object of classification; a polynomial function is set by a CPU as computing means within the information processing apparatus so as to classify the binary data into two classes; and a column vector a which satisfies diag(y)D^na>0 is computed by using the CPU, where a represents a column vector having a coefficient of each term of the set polynomial function as an element, D^n represents a matrix determined on the basis of a combination of the values taken by the respective terms, and V represents a row vector having as an element the value of a class to which binary data should be classified when the binary data is given so that a polynomial function having terms in a number fewer than $3\times2^{n-2}$ is obtained.

2. (canceled)

3. A data classification device: for setting a function to define a binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; computing the value of the function by substituting the set function with respective elements of the given binary data; and carrying out classification of the binary data on the basis of the value of the computed function; comprising:

means for accepting binary data in which a value of each element is 1 or −1;

means for setting a polynomial function by using a CPU as a computing device so as to classify the binary data into two classes; and

means for computing a column vector a which satisfies diag(y)D^na>0 by using the CPU, where a represents a column vector having a coefficient of each term of the set polynomial function as an element, D^n represents a matrix determined on the basis of a combination of the values taken by the respective terms is D^n, and V represents a row vector having as an element the value of a class to which binary data should be classified when the binary data is given,

wherein, by these means, a polynomial function having terms in a number fewer than $3\times2^{n-2}$ is obtained.

4. (canceled)

5. A computer program, which allows a computer to set a function to define binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; and to compute the value of the function by substituting the set function with respective elements of the given binary data; and to carry out classification of the binary data on the basis of the value of the computed function; comprising a step of:

allowing the computer to compute a column vector a which satisfies diag(y)D^na>0 by using a CPU as computing means within the computer, where a represents a column vector having a coefficient of each term of the set polynomial function as an element, D^n represents a matrix determined on the basis of a combination of the values taken by the respective terms, and y represents a row vector having as an element the value of a class to which binary data whose elements have a value of 1 or −1 should be classified when the binary data is inputted in the computer; and

allowing the computer to set a polynomial function having terms in a number fewer than $3\times2^{n-2}$, by using the CPU so as to classify the binary data into two classes by using the column vector a, which is computed by the above step.

6. (canceled)

7. A computer readable storage medium storing a computer program which allows a computer to set a function to define a binary data made of n pieces (n is an integer number not less than 2) of elements as an input value; and to compute the value of the function by substituting the set function with the respective elements of the given binary data; and to carry out classification of the binary data on the basis of the value of the computed function;

wherein the storage medium stores a computer program, comprising a step of:

allowing a computer to compute a column vector a which satisfies diag(y)D^na>0 by using a CPU as a computing device within the computer, where a represents a column vector having a coefficient of each term of the set polynomial function as an element, D^n represents a matrix determined on the basis of a combination of the values taken by the respective terms, and y represents a row vector having as an element the value a class to which binary data whose elements have a value of 1 or −1 should be classified when the binary data is inputted in the computer, and

allowing the computer to set a polynomial function having terms in a number fewer than $3\times2^{n-2}$, by using the CPU so as to classification the binary data into two classes by using the column vector a, which is computed by the above step.

8. (canceled)

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