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[54] **BIOMETRIC CONTROLLED KEY GENERATION**

[75] Inventors: **George J. Tomko**, East York; **Colin Soutar**; **Gregory J. Schmidt**, both of Toronto, all of Canada

[73] Assignee: **Mytec Technologies, Inc.**, Don Mills, Canada

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,541,994.

[21] Appl. No.: **512,491**

[22] Filed: **Aug. 8, 1995**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 301,677, Sep. 7, 1994, Pat. No. 5,541,994.

[51] **Int. Cl.^{6}** **H04K 9/00**

[52] **U.S. Cl.** **380/23**; 380/25; 380/4; 380/30

[58] **Field of Search** 380/3, 4, 23, 25, 380/30

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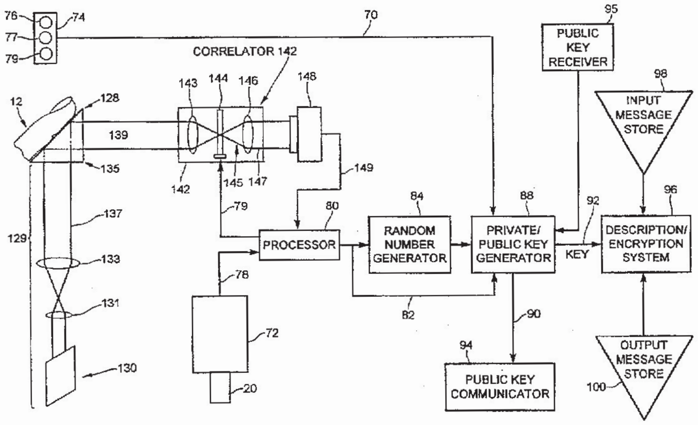
Primary Examiner—David C. Cain

Attorney, Agent, or Firm—Merchant, Gould, Smith, Edell, Welter & Schmidt, P.A.

[57] **ABSTRACT**

A key generation system is implemented as follows. In an enrolment apparatus, a unique number for use with PIN operated machines or public key cryptography systems is generated by manipulation of fingerprint information of a subscriber. A filter is then generated which is a function both of the Fourier transform of the subscriber's fingerprint(s) and of the unique number. This filter is stored on a subscriber card. When the subscriber wishes to generate his key, he inputs his card to a card reader of an apparatus and places his finger(s) on a fingerprint input. The apparatus generates an optical Fourier transform from the fingerprint input. The Fourier transform signal is incident on to a spatial light modulator programmed with the filter information from the card. An inverse transform is generated from the filtered signal and this is used to regenerate the key that will be used as the PIN in a PIN operated device, or as the private key cryptography system.

55 Claims, 4 Drawing Sheets



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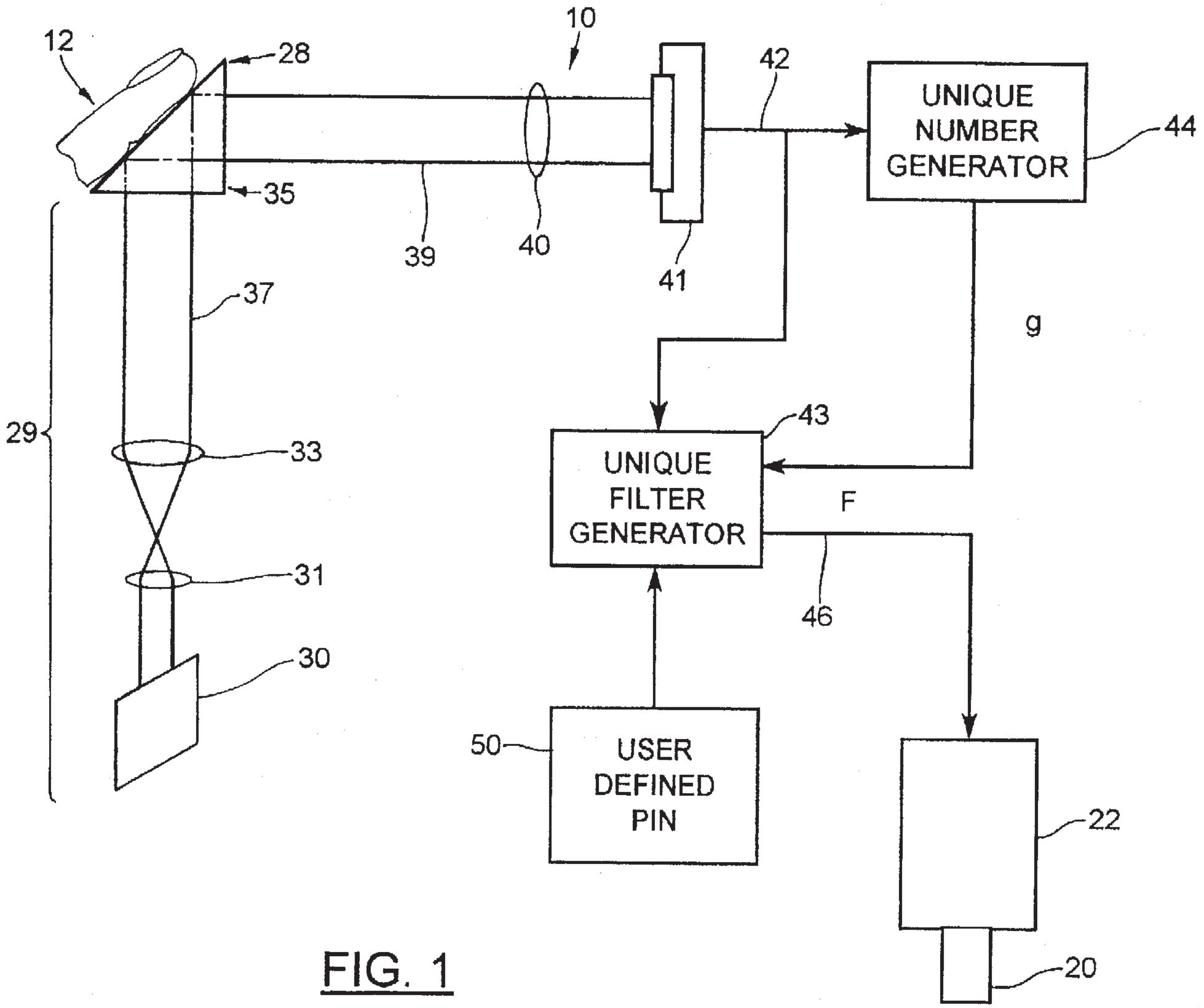
12
28
10
42
UNIQUE NUMBER GENERATOR
44
35
39
40
41
37
g
29
43
UNIQUE FILTER GENERATOR
33
F
31
46
30
50
USER DEFINED PIN
22
20

FIG. 1

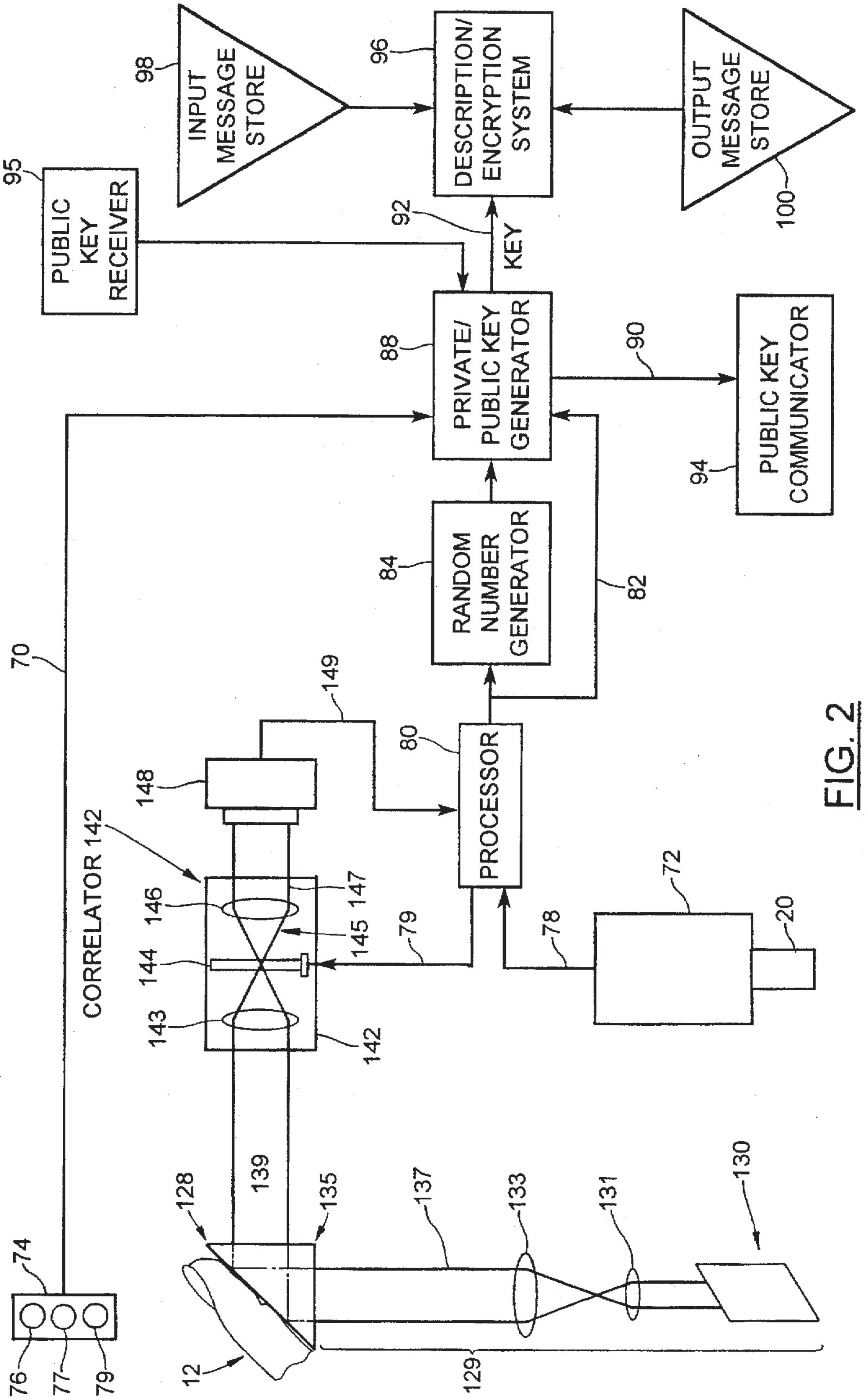
INPUT MESSAGE STORE
98
DESCRIPTION/ ENCRYPTION SYSTEM
96
OUTPUT MESSAGE STORE
100
PUBLIC KEY RECEIVER
95
92
KEY
PRIVATE/ PUBLIC KEY GENERATOR
88
90
PUBLIC KEY COMMUNICATOR
94
RANDOM NUMBER GENERATOR
84
82
70
149
80
PROCESSOR
148
CORRELATOR 142
146
147
145
144
79
143
142
78
72
20
74
76
77
79
128
139
135
137
133
131
130
12
129

FIG. 2

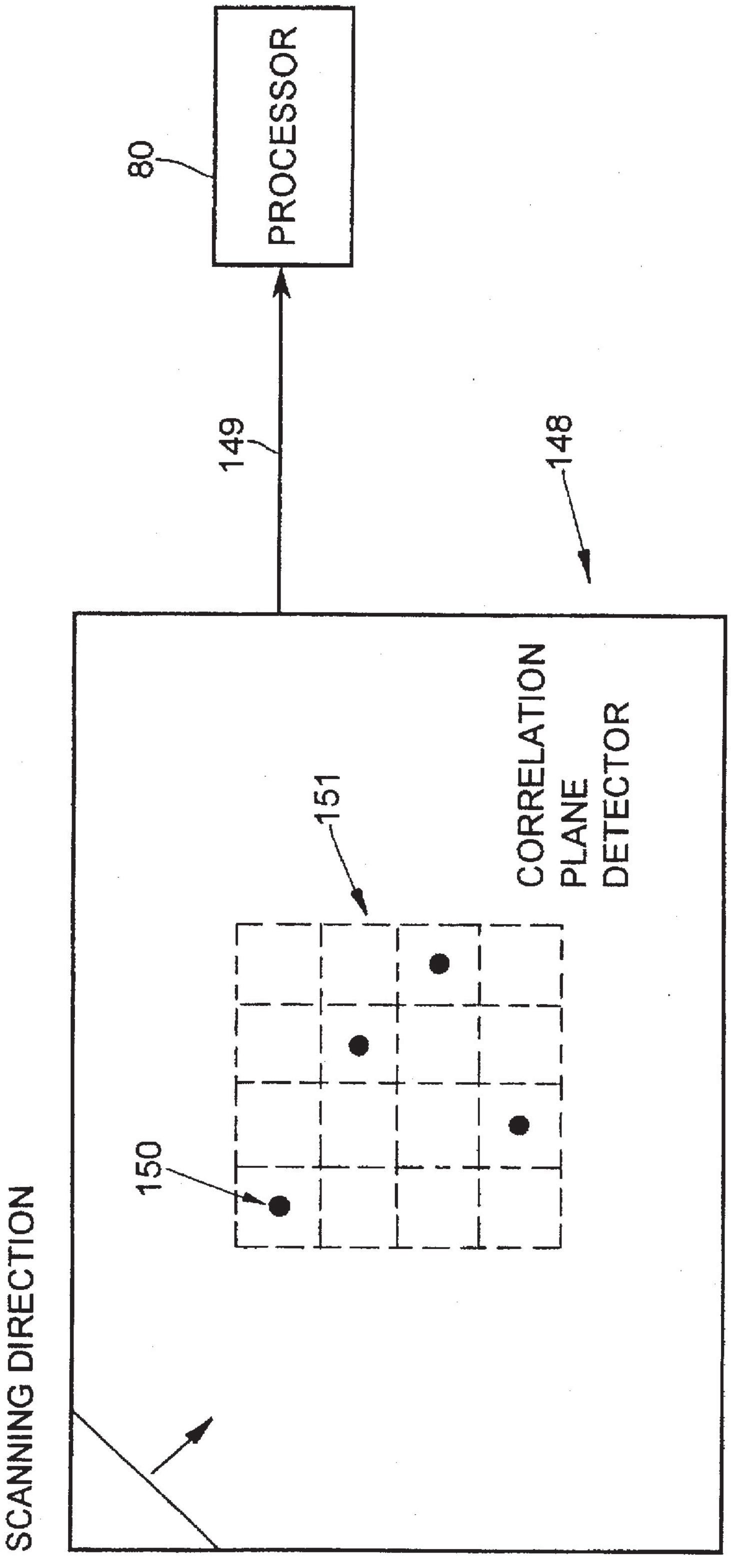
80
PROCESSOR
149
148
CORRELATION
PLANE
DETECTOR
151
150
SCANNING DIRECTION

FIG. 3

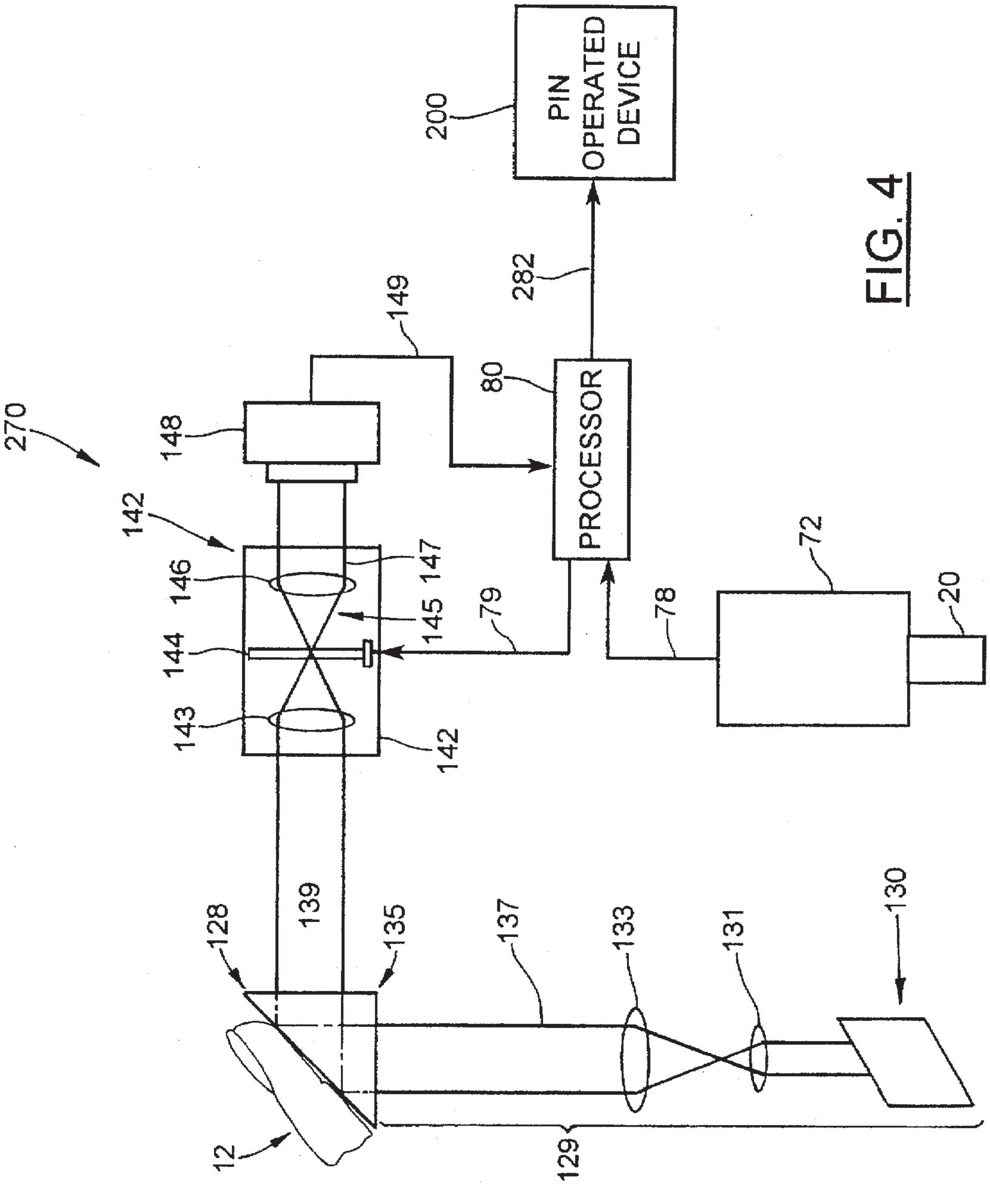
270
142
148
149
146
147
145
144
143
142
79
80
PROCESSOR
282
200
PIN OPERATED DEVICE
72
78
20
128
139
135
137
133
131
130
12
129

FIG. 4

BIOMETRIC CONTROLLED KEY GENERATION

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation in part of application Ser. No. 08/301,677 filed Sep. 7, 1994 now U.S. Pat. No. 5,541,994.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a system for generating a key under the control of a biometric, such as a fingerprint. The system has application in a public key cryptographic system and for devices requiring a personal identification number (PIN) for operation.

2. Description of the Related Art

In a public key cryptosystem, a plain text message may be encrypted by inputting the message and an enciphering key to an encryption algorithm. To decipher the message, the encrypted message is input to the inverse of the same algorithm along with a deciphering key. As with many encryption techniques, the encryption algorithm effects transformations of the plain text message which are so complicated it is computationally infeasible to reverse the process even if the algorithm is known. A peculiarity of public key systems is that it is also computationally infeasible to determine the deciphering key from the enciphering key. Consequently, in a public key cryptosystem, both the algorithm and the enciphering key may be made available to the public without jeopardising the security of a message enciphered with the enciphering key. Hence the term "public key" for the enciphering key. The deciphering key, which is confidential, is known as a "private key". With a public key system, anyone who wishes to receive encrypted messages may make an encryption algorithm and a public key freely available. Moreover, some public key systems allow the transmission of a "digital signature" that prevents forgery of messages by a receiver as well as a third party.

By way of example, with the known "knapsack" cryptosystem, a public key is derived from a private key utilising modular arithmetic. Each element in the array (vector) forming a private key is multiplied by a large prime number, x, and divided by a second large prime number, y. The corresponding element of the public key vector is the remainder from this operation. In order to encrypt a plain test message, the message is digitised and the digital string grouped into arrays (vectors) each having the same number of elements as the number of elements in the array which comprises the public key. The encrypted message is formed from the vector dot product of the public key vector with each vector formed from the digitised plain text message.

Clearly the exemplary encryption technique and the technique for deriving a public key from a private key make it computationally infeasible to determine either the private key of the plain text message even though the algorithm, along with the encrypted text, is known. There are, however, known techniques for structuring a private key vector such that, with it, the plain text can be rapidly derived from an encrypted message. Two sample techniques in this regard are described in an article entitled 'The Mathematics of Public-Key Cryptography" *Scientific American* August 1979, pages 146 to 157.

The problem with such public key cryptograph systems is that, in use, they require a secure, yet readily available, private key. The private key has to either be remembered, which is not practical, or stored in a secure place and retrieved. The security of storage therefore is at best dependent on password access which itself can be compromised.

A number of devices, such as automated teller machines (ATMs) and symmetric encryption/decryption systems, require the entry of a PIN for operation. A PIN therefore acts a private key which permits operation of such devices. Devices requiring a data key for operation share the same problem as identified for public key cryptographic systems: the data key must be secure and yet readily available. To mitigate this problem, PIN operated devices often utilize a short key which may be memorized by the user. However, not all users do memorize their PIN and, in any event, use of a short PIN reduces the security of the PIN operated device.

This invention seeks to overcome drawbacks of the known prior art and provide an extremely secure private key which is not even known by the user yet is readily accessible.

SUMMARY OF THE INVENTION

According to the present invention, there is provided a biometric controlled key generation system, comprising: a body part input for generating an optical information signal impressed with a biometric; Fourier transform means along a path of said optical information signal to obtain a Fourier transform representation of said information signal; a programmable filter responsive to said Fourier transform means for filtering said Fourier transform representation of said information signal to obtain a filtered Fourier transform representation; means for reading data from a data carrier storing filter information and for programming said programmable filter with said filter information data; inverse transform means responsive to said filter to inverse Fourier transform said filtered Fourier transform representation to obtain an inverse transform representation; key generating means responsive to said inverse transform means for generating a private key.

According to another aspect of this invention, there is provided a method for generating a private key, comprising the steps of: generating an optical information signal impressed with a biometric; obtaining a Fourier transform representation of said information signal; receiving a filter and filtering said Fourier transform representation; information signal with said filter to obtain a filtered Fourier transform representation; obtaining an inverse Fourier transform representation of said filtered Fourier transform representation; generating a private key from said inverse transform representation.

BRIEF DESCRIPTION OF THE DRAWINGS

In the figures which disclose example embodiments of the invention,

FIG. 1 is a schematic diagram of an enrolment apparatus made in accordance with this invention,

FIG. 2 is a schematic diagram of an encrypting/decrypting apparatus made in accordance with this invention,

FIG. 3 is a schematic diagram of a portion of FIG. 2, and

FIG. 4 is a schematic diagram of a PIN generating apparatus made in accordance with this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following, lower case letters represent functions in the "spatial domain" and upper case letters represent the

"Fourier transformed frequency domain". Also, we use the following terminology: "Fourier transform" denotes a transformation from the spatial domain to the frequency domain, and "inverse Fourier transform" denotes a transformation from the frequency domain to the spatial domain. It should be noted that when the inverse Fourier transform is implemented optically (using a lens), the transformation is in fact equivalent to the Fourier transform. The consequence of this is that a coordinate reversal occurs in the resulting, spatial domain. On the other hand, digital implementation of the inverse Fourier transform can be accomplished as mathematically defined, and so no such coordinate reversal occurs. However, both (optical and digital) implementations of the inverse Fourier transform can be used to produce the correlation operation which is required for this invention.

An individual who wishes to use the encrypting and decrypting apparatus of this invention is enroled by way of enrolment apparatus **10** of FIG. **1**. With reference to FIG. **1**, enrolment apparatus **10** comprises an input system **29** with a light source **30**, which may be a coherent source, an expander lens **31**, and a collimator lens **33** to illuminate a prism **35** with a beam **37**. One face of the prism forms an input screen **28**. The individual to be enroled places a finger (or fingers) **12** on the input screen. The input system utilized the principle of total internal reflection to read the pattern formed by the furrows of the input fingerprint pattern. That is, a furrow will create an air space over the surface of a glass screen, allowing light which is internally reflected from the interior surface of the screen to proceed unimpeded. Ridges, however, will be in contact with the surface, where they will scatter and absorb a portion of the illuminating light. This effect is known as frustrated total internal reflection. In the result, the output beam **39** from the prism is an information beam carrying the fingerprint pattern, p. The optical beam **39** inputs a lens **40** which images the fingerprint information onto an Image Capture and Digitizer Device ICDD, **41**, comprising a light detector array, and A/D converter and a processor. The ICDD converts the optical fingerprint information beam into a two-dimensional grey scale digital representation. The digital output **42** of the ICDD is input to a unique filter generator **43** and to a unique number generator **44**.

The unique number generator **44** generates an array of numbers. This may be accomplished in any of a number of ways. For example, a Fourier transform of the fingerprint information may be calculated to obtain the Fourier transform co-efficients of the transform. Selected ones of these Fourier transform co-efficients may then be chosen and combined to generate a number u. It will be apparent that this number u is unique for any single placement of the particular fingerprint(s) on the input screen. Alternatively, u can be generated by a random number generator seeded with the selected Fourier transform co-efficients. The unique number u is the used to generate an array of number g={g_1, . . . g_n} such that the values in the elements of g represent the unique number u. For example, if u is a k-digit base 10 number and if in any subsequent measurement of the values g_1, . . . g_n, the detecting instrument will have a known error in detection which only allows β distinct values from 0 to m−1 inclusive (m is the dynamic range of the detector), n would be chosen to be the integer greater than or equal to $\log_\beta 10^k$. The unique number u can then be expanded into elements of g by using modulo division, i.e.:

$$g_1 = \text{Integer of } \frac{u}{\beta^{n-1}}$$

-continued

$$g_2 = \text{Integer of } \frac{u \bmod \beta^{n-1}}{\beta^{n-2}}$$

$$g_3 = \text{Integer of } \frac{(u \bmod \beta^{n-1})}{\beta^{n-3}} - \text{Integer of } \frac{u \bmod \beta^{n-2}}{\beta^{n-3}}$$

etc. The array, g, is input to the unique filter generator **43**.

The unique filter generator **43** calculates the digital Fourier transform, P, of the fingerprint information and generates a two dimensional filter function, F, as follows. The mathematical multiplication of the fingerprint transform, P, with the filter, F, produces the two-dimensional light distribution S. F is generated so that the inverse Fourier transform of S, denoted by s, is equal to a series of n displaced delta-like functions $\delta_1, \delta_2, \ldots \delta_n$, where the square of the amplitude of δ_1 is equal to the corresponding value g_1 in the array g. This may be represented mathematically by the following acts of equations which for convenience will be described in one dimension:

Let

p(x) be the input fingerprint pattern signal

P(u) be the complex Fourier transform of the signal, denoted by |P(u)|exp(jϕ(u)), where ϕ(u) is the phase of the Fourier transform

F(u) be the filter function

and

s(x) be the output signal

We desire s(x) to have the following form:

$$s(x) = \sqrt{g_1} \cdot \delta(x-x_1) + \sqrt{g_2} \cdot \delta(x-x_2) + \ldots \sqrt{g_n} \cdot \delta(x-x_n)$$

that is n delta functions at positions $x_1, x_2, \ldots x_n$ and relative intensities $g_1, g_2, \ldots g_n$ respectively

Then,

$$\begin{aligned} S(u) &= \int\sqrt{g_1} \cdot \delta(x-x_1) \cdot \exp(-j2\pi ux)dx + \\ &\quad \int\sqrt{g_2} \cdot \delta(x-x_2) \cdot \exp(-j2\pi ux)dx + \ldots \end{aligned}$$

Let $x' = x - x_1$, $x'' = x - x_2$, etc.

$$\begin{aligned} S(u) &= \int\sqrt{g_1} \cdot \delta(x') \cdot \exp(-j2\pi u(x'+x_1))dx' + \\ &\quad \int\sqrt{g_2} \cdot \delta(x'') \cdot \exp(-j2\pi u(x''+x_2))dx'' + \ldots \\ &= \sqrt{g_1} \cdot \exp(-j2\pi ux_1) \cdot \int\delta(x') \cdot \exp(-j2\pi ux')dx' + \\ &\quad \sqrt{g_2} \cdot \exp(-j2\pi ux_2) \cdot \int\delta(x'') \cdot \exp(-j2\pi ux'')dx'' + \ldots \\ &= \sqrt{g_1} \cdot \exp(-j2\pi ux_1) + \sqrt{g_2} \cdot \exp(-j2\pi ux_2) + \ldots \end{aligned}$$

We require that

$$P(u) \cdot F(u) = S(u)$$

$$\text{Thus, } F(u) - \frac{S(u)}{P(u)}$$

That is,

$$F(u) = \frac{\sqrt{g_1} \cdot \exp(-j2\pi ux_1) + \sqrt{g_2} \cdot \exp(-j2\pi ux_2) + \ldots \sqrt{g_n} \exp(-j2\pi ux_n)}{|P(u)|\exp(j\phi(u))}$$

-continued

$$= \frac{\exp(-j\phi(u))}{|P(u)|} \cdot [\sqrt{g_1} \exp(-j2\pi u x_1) + \sqrt{g_2} \exp(-j2\pi u x_2) + \ldots]$$

In general |P(u)|=0 will occur for some values of u, resulting in singularities in the above expression for F(u). This problem is usually eliminated by imposing a magnitude constraint on F(u), such that

$$F(u) = \begin{cases} \frac{\alpha\exp(-j\phi(u))}{|P(u)|} \cdot [\sqrt{g_1} \exp(-j2\pi u x_1) + \sqrt{g_2} \exp(-j2\pi u x_2) + \ldots] \text{ for } |P(u)| \geqq \alpha \\ \exp(-j\phi(u)) \cdot [\sqrt{g_1} \exp(-j2\pi u x_1) + \sqrt{g_2} \exp(-j2\pi u x_2) + \ldots] \text{ otherwise} \end{cases}$$

where α is a constant that ensures that |F(u)| is normalized. This complex-valued filter function, F, will be implemented on the available spatial light modulator using the methods described in the article "Optimal realizable filters and the minimum Euclidean distance principle," Richard D. Juday, Applied Optics, Vol. 32 pages 5100–5111 (1993), or by other such methods.

One knowledgeable in the art can easily extend this to two dimensions. The unique filter generator outputs the values of the filter F to card storage device **22** on line **46**. The card storage device stores filter F on a storage medium (such as a magnetic strip or smart card chip) of a card **20**. Once this operation is accomplished, enrolment is complete and the individual leaves with card **20**.

A subscriber may communicate his public key or decrypt a message utilizing apparatus **70** of FIG. **2**. Further, another may encrypt a message with apparatus **70**.

Turning to FIG. **2**, apparatus **70** comprises an input system **129** with a laser **130**, expander lens **131**, collimator lens **133**, and prism **135** which may be similar to the input system **29** of FIG. **1**. A correlator **142** is in the information beam path **139**. The correlator comprises a Fourier transforming lends **143**, an electronically addressable (programmable) spatial light modulator (SLM) **144** in the back focal plane of lens **143**, and an inverse Fourier transform lens **146**. The output beam **147** from the correlator inputs optical detector **148**. Detector **148** inputs processor **80** on line **149**. The processor also receives an input from card reader **72** on line **78**. The processor outputs to the SLM **144** on line **79**, to a pseudo-random number generator **84**, and to a public/private key generator **88** on line **82**. The pseudorandom number generator outputs to the public/private key generator which, in turn, outputs to a public key communicator **94** and, on line **92**, to a decryption/encryption system **96**. The public/private key generator also receives an input from public key receiver **95** and from keypad **74**. The decryption/encryption system receives an input from an input message store **98** and outputs to an output message store **100**.

A subscriber who wishes to transmit his public key places the same finger or fingers on the input screen **128** as were placed on the screen **28** (FIG. **1**) during enrolment, his card **20** in reader **72**, and presses button **76** of keypad **74**. This activates light source **130** and the resulting output beam **139** from the prism is an information beam carrying the fingerprint pattern p'. The beam **139** carrying the spatial fingerprint information proceeds into the correlator **142** and passes through the Fourier transform lens **143**. The filter information, F, stored on card **20** is read by reader **72** and input to processor **80**. The processor converts the incoming digital filter information signals to analog SLM drive voltages. These drive voltages, which represent the filter information, are transferred into the SLM **144** on line **79**. The filter written on the SLM **144** modulates the fingerprint's optical transform through a multiplicative method which is part of the optical correlation operation which compares the subscribers fingerprint(s) with those represented by the encoded filter F stored on the subscriber's card. The output form the SLM **144** is an optical signal S' whose similarity to the transform function S depends on the degree of correlation between the input fingerprint(s) p' and the reference fingerprint(s) p used to construct the filter F. If p and p' are the same fingerprint(s) the S' equals S. The optical signal **145** which comprises S' passes through the second transform lens **146** and onto the optical detector **148** where its intensity distribution s' is detected. When p' equals p then s' will be an intensity distribution representing g, the array of numbers which represent the unique number u. The output of the optical detector **148** inputs the processor **80** which calculates the unique numbers u from the array of numbers $\{g_1, \ldots g_n\}$. If the error in detection by detector **148** only allows β distinct values between 0 and m−1 inclusive, where m is the dynamic range of the optical detector **148**, we calculate:

$$g_i^* = g_i(\text{measured}) \cdot \beta/m \text{ and round to integers}$$

$$\text{where } 0 \leqq g_i^* < \beta.$$

$$\text{Then } u = g_1^* \beta^{n-1} + g_2^* \beta^{n-2} + \ldots + g_n^* \beta^0$$

The number u then acts as the seed number which inputs pseudo-random number generator **84**. It is important to note that the pseudo-random number generator will generate the same random numbers whenever it is input with the same seed, in this case u. The random numbers derived by pseudo-random number generator **84** as well as u itself, on line **82**, input the key generator **88**. The key generator utilizes known public-key cryptographic techniques to derive a private key or a public key from these inputs. With button **76** of keypad **74** depressed, the key generator is prompted to output the public key on line **90** to public key communicator **94**. Communicator **94** may simply be a display or it could be a transmitter such as a modem which transmits the number to a sendec.

If a subscriber has an encrypted message he wants to decipher, he may utilize apparatus **70** to decrypt same, as follows. The encrypted message is input to input message store **98**. Then the subscriber (receiver) inserts his card **20** in card reader **72**, depresses button **79** of keypad **74**, and places his finger(s) on input screen **128**. As before, the processor **80** generates the unique number u from the intensity distribution s' and this, along with the random numbers generated by random number generator **84** in response to the seed number u, input the key generator **88**. In response to the prompt from button **79**, the key generator utilizes these inputs to derive the private key. The private key then inputs decryption/encryption system **96** on line **92**; the encrypted message stored in the input message store **98** also inputs system **96**. The system **96** utilizes known public key cryptographic techniques to decrypt the message from these inputs. The decrypted message is then output to output message store **100** where it may be accessed by the subscriber.

If the person using apparatus **70** was not the person whose fingerprints were represented by the encoded filter F, then the optical signal S' derived from the multiplication of the filter F from the card with the Fourier transform P' of that persons fingerprint(s) will not equal S. This will mean that the unique number u' indirectly derived from S' will not be equivalent to u. Consequently the key generated by the private/public key generator **88** will not decrypt the encrypted message.

An individual may send a subscriber an encrypted message utilizing apparatus **70** in the following manner. The individual stores a plain text message in input message store **98**, depresses button **77** of operator input **74** and inputs the public key of the subscriber to public key receiver **95**. This prompts the key generator **88** to directly input the public key from public key receiver **95** to the decryption/encryption system **96**. The system **96** uses this key in encrypting the plain text message and outputs the encrypted message to output message store **100**. The individual may then transmit the encrypted message to the subscriber in any non-secure manner. (It may be noted that the fingerprint and card reading subsystems of apparatus **70** are inactive when button **77** is pressed.)

It will be apparent that the system of this invention allows the use of public key encryption techniques without a subscriber knowing his private key. This enhances the security of the system. Yet further a lost card could not be used by a third party in apparatus **70** because the unique number u is only recoverable by inputting the subscriber's fingerprint.

Another advantage of the subject system is that the subscriber need not know his public key as it may be easily generated with the system of the invention. Furthermore, if an unauthorized individual broke in to an apparatus **70** of FIG. **2**, he would have no way of determining the manner for generation of u since this number is only generated in the enrolment devices of FIG. **1** and is unique to each individual.

The robustness of the system of the present invention may be enhanced as follows. In the enrolment apparatus **10** of FIG. **1**, the absolute value of one point of $g=\{g_1, \ldots g_n\}$, for example g_1, may be stored on card **20**. If this is done, then the processor circuit **80** of FIG. **2** may compare the intensity of this same point in the g function generated by optical correlator **142** with that point stored on the card and scale the elements of g from correlator **142** accordingly. This will reduce the effect of the "noise" present in apparatus **70**. For example, dirt or oil on the input screen **128** could reduce the absolute intensity of g. However, the relative intensities of the delta functions would be preserved. The absolute value could then be recovered by comparing one point of g generated by correlator **142** with that same point of g which is stored in absolute form on card **20**.

In another embodiment of the invention, the unique number, u, is related to the location of peaks in the correlator output, rather than their relative intensities as considered so far. In this embodiment the filter F is designed to produce a series of equal-intensity peaks at the correlation plane detector. The peak locations are carefully controlled so that the occur within a grid of p by q cells on the detector. When n such series of peaks are displayed sequentially, the unique number u can be reproduced, using only the peak location information.

In this embodiment an individual will be enroled using the following procedure. With reference to FIG. **1**, the individual will place their finger(s) on the input screen **28**. As before, the fingerprint information is input to eh ICDD **41**. The digital output **42** of the ICDD is input to the unique filter generator **43** and to the unique number generator **44**. The unique number generator **44** will assign the subscriber a unique number u as previously described. Then, the unique number generator **44** determines an array b which is related to the unique number u by the following relationship:

$$u=f(b,w)$$

where w is a constant for any specified number of peaks (t) and size of grid (p by q) as described hereinafter. For reasons which will also be apparent hereinafter, a convenient choice for the function is:

$$u=b_1w^{n-1}+b_2w^{n-2}+\ldots+b_{n-1}w^1+b_nw^0$$

Thus, the coefficients b_1, b_2. . . b_n which determine the unique number u can be evaluated using modular arithmetic as follows:

$$b_1=\text{Integer of}\frac{u}{w^{n-1}}$$

$$b_2=\text{Integer of}\frac{u \bmod w^{n-1}}{w^{n-2}}$$

$$b_{n-1}=\text{Integer of}\frac{u \bmod w^2}{w^1}$$

$$b_n=\text{Integer of}\frac{u \bmod w^1}{w^0}$$

The unique number generator **44** then assigns each value of b_1 to one of the possible permutations of arranging t peaks in a grid of p by q cells. One of the peaks is always located in the upper left cell of the grid, to serve as a reference peak. The number of permutations of locating the remaining t−1 peaks in the p·q−1 cells is given w, where:

$$w=\frac{(p\cdot q-1)!}{(t-1)!(p\cdot q-t)!}$$

Thus, it is clear that each coefficient b_1 has a value between 0 and w−1 inclusive. The assignment of the value of b_1 to a particular pattern of peak locations is accomplished by using a randomised look-up table in the filter generator which relates every possible value of b_1(i.e. from 0 to w−1) to a unique permutation of peak locations in the grid. Thus, a two-way relationship between the value of b_1 and the relative locations of peaks in the grid is established. Clearly then, if the subscriber can later reproduce the pattern of peaks in such a grid using the apparatus **70** of FIG. **2**, then the unique number u can be regenerated and thus the subscriber can proceed. Note however, that because of the randomised look-up table, even if a pattern of peaks were discerned, it would bear no relationship to the corresponding value of the element of b unless the look-up were known.

The required locations of the peaks for each element, b_i, of b are input to the unique filter generator from the unique number generator. The unique filter generator calculates the filter, F_i, so that when the correct fingerprint (or fingerprints), p, is input to apparatus **70** of FIG. **2**, the output functions, s_i, is the specified arrangement of equal-intensity peaks. This calculation uses the Fourier transform of the subscriber's fingerprint(s), P, and the same approach as described previously, with the exception that all of the delta-like functions are assigned the same peak height, and their relative locations are determined by b_i. (Therefore, in one dimension,

$$s_i = \delta(x-x_1) + \delta(x-x_2) + \ldots + \delta(x-x_t)$$

where $x_1, x_2, \ldots, x_t$ are determined by the look-up table of peak locations for b_i.) Note that n such filters, $F_1, F_2, \ldots F_n$, corresponding to $b_1, b_2, \ldots b_n$, will be required to determine all the elements of b. The n filters are generated in this manner, and are then stored on the card **20**. Thus, the enrolment process is completed and the user retains the card **20**.

Where the subscriber to the system wishes to regenerate the unique number, u, to produce the private or public key, the following procedure is adopted. Turning to FIG. **2**, when a subscriber places his finger(s) on the input **128** of apparatus **70**, inserts his card **20** in the reader **72**, and presses button **76** (to display his public key) or **79** (to decrypt a message), the processor causes the n filters from the card **20** to be transferred sequentially to the SLM **144** on line **79**. A given filter, F_1, is multiplied in the correlator **142** with the Fourier transform, P, of the subscriber's fingerprint(s). The inverse Fourier transform of the result, which is the function s_i, is displayed on the correlation plane detector **148**. With reference to FIG. **3**, which schematically illustrates a portion of FIG. **2**, the location of the first peak **150** in the detector **148** is determined by scanning across the detector from upper left to the bottom right. This first peak is considered to be the reference peak, and its position defines the grid **151** of p by q detection cells in the correlation plane detector, with the reference peak occupying the upper left cell in this grid. The detector output is then scanned over the are of the grid **151** and the locations of the other t–1 peaks are determined. Each of the t–1 peaks occupies a unique cell in the grid and the position of each is communicated to the processor **80** on line **149**. The processor determines the element b_i of the vector b from the pattern of peaks by referring to the same randomised look-up table as used in the unique filter generator **43**. The next filter, F_i, is then written to the SLM and thus the next element of b is determined and son on, until the entire array, b, is generated.

Since each element b_i, will have w possible values, b_i, is, in effect, a number in base w. It is for this reason that

$$u = f(b,w)$$

is chosen as

$$u = b_1 w^{n-1} + b_2 w^{n-2} + \ldots + b_{n-1} w^1 + b_n w^0,$$

because this equation converts the n elements of b from base w to base 10 which is more suitable for communication purposes. Thus, the unique number u is recreated using the apparatus **70** of FIG. **2**, and can be input to the pseudorandom number generator.

In the example shown in FIG. **3**, t=4 (there are 4 peaks), p=q=4 (a 4×4 detection grid is defined), and n=4 (4 filters are displayed sequentially). Thus, in this example, the unique number u would be capable of representing 455^4 or 4.3×10^{10} values.

This embodiment of the invention has the advantage of requiring only a binary search for correlation peaks, without regard to their intensity. It will thus be more resistant to any variations in the correlation peak heights caused by the correlator system noise.

A further embodiment of the invention would use the combination of peak height and location to generate the unique number, u, using the procedures described herein.

A subscriber may use his card created with the enrolment device of FIG. **1** to operate a PIN operated device, such as an ATM or a symmetric encryption/decryption system, utilizing apparatus **270** of FIG. **4**. with regard to FIG. **1**, the PIN may be derived from the unique number generator **44** or can be chosen by the system user **50**.

Turning to FIG. **4** in which like parts to those appearing in FIG. **2** have been given like numbers, apparatus **270** comprises an input system **129** with a laser **130**, expander lens **131**, collimator lens **133**, and prism **135**. A correlator **142** is in the information beam path **139**. The correlator comprises a Fourier transforming lens **143**, an electronically addressable (programmable) spatial light modulator (SLM) **144** in the back focal plane of lens **143**, and an inverse Fourier transform lens **146**. The output beam **147** from the correlator inputs optical detector **148**. Detector inputs processor **80** on line **149**. The processor also receives an input from card reader **72** on line **78**. The processor outputs to the SLM **144** on line **79** and to a PIN operated device **200** on line **282**.

A subscriber who wishes to use the PIN operated device places the same finger or fingers on the input screen **128** as were placed on the screen **28** (FIG. **1**) during enrolment and his card **20** in reader **72**. This activates light source **130** and the resulting output beam **139** from the prism is an information beam carrying the fingerprint pattern p'. The beam **139** carrying the spatial fingerprint information proceeds into the correlator **142** and passes through the Fourier transform lens **143**. The filter information, F, stored on card **20** is read by reader **72** and input to processor **80**. The processor converts the incoming digital filter information signals to analog SLM drive voltages. These drive voltages, which represent the filter information, are transferred into the SLM **144** on line **79**. The filter written on the SLM **144** modulates the fingerprint's optical transform through a multiplicative method which is part of the optical correlation operation which compares the subscribers fingerprint(s) with those represented by the encoded filter F stored on the subscriber's card. The output from the SLM **144** is an optical signal S' whose similarity to the transform function S depends on the degree of correlation between the input fingerprint(s) p' and the reference fingerprint(s) p used to construct the filter F. If p and p' are the same fingerprint(s) then S' equals S. The optical signal **145** which comprises S' passes through the second transform lens **146** and onto the optical detector **148** where its intensity distribution s' is detected. When p' equals p then s' will be an intensity distribution equal to g, the array of numbers which represent the unique number u. The output of the optical detector **148** inputs the processor **80** which calculates the unique number u from the array of numbers $\{g_1, \ldots g_n\}$. If the error in detection by detector **I48** only allows β distinct values between 0 and m–I inclusive, where m is the dynamic range of the optical detector **148**, we calculate:

$$g_i^* = g_i(\text{measured}) \cdot \beta/m \text{ and round to integers}$$

$$\text{where } 0 \leqq g_i^* < \beta.$$

$$\text{Then } u = g_1^* \beta^{n-1} + g_2^* \beta^{n-2} + \ldots + g_n^* \beta^o$$

The number u then acts as the PIN (which is a type of private encryption key) for operating PIN operated device **200**. Thus, the fingerprint of an authorised user will recover his PIN from his card without need for the user to know his PIN. On the other hand, because the PIN is secured by the fingerprint, the user may choose his/her own PIN for use with the PIN operated system.

The unique number u can also be generated using peak locations in the output of the correlator as described in a previous embodiment.

It will be apparent to those skilled in the art that input systems other than system **29** of FIG. **1** and **129** of FIGS. **2** and **4** are available in order to produce a fingerprint information beam. Some of these other systems do not require a laser.

While it is preferred that the input to the input system is the fingerprint(s) of a user, the input system could be adapted to produce an optical signal impressed with characteristics from other body parts, such as a user's hand or iris. Indeed, any body part which has a unique signature comprises a biometric which may be suitable for use within the spirit of this invention.

While the systems of FIGS. **2** and **4** have been described in conjunction with an optical correlator **142**, it will be apparent to those skilled in the art that the correlator may be implemented digitally.

Other modifications will be apparent to those skilled in the art and, accordingly, the invention is defined in the claims.

What is claimed is:

1. A biometric controlled key generation system, comprising:

a body part input for generating an information signal bearing biometric information from a body part;

means for reading comparison data from a data carrier, said comparison data comprising private key data encrypted by biometric data; and

means for comparing said information signal with said comparison data for recovering said private key data from said comparison data.

2. A biometric controlled private key encoding system, comprising:

a body part input for generating an information signal bearing biometric information from a body part;

means to generate a function based on one of said private key and a unique number from which said private key may be derived;

means to generate biometric data from said information signal;

means to encrypt said function with said biometric data to generate comparison data; and

means for storing said comparison data on a data carrier.

3. The key generation system of claim **1** including means for storing said comparison data on said data carrier, comprising:

a further body part input for generating a further information signal bearing biometric information from said body part;

means to generate a function based on one of said private key and a unique number from which said private key may be derived, said array comprising said private key data;

means to generate biometric data from said further information signal;

means to encrypt said array with said biometric data to generate said comparison data; and

means for storing said comparison data on said data carrier.

4. The key generation system of claim **3** including key generating means for generating a private key from said private key data.

5. The key generation system of claim **4** wherein said means to generate a function is based on said unique number and wherein said key generating means comprises means to recover said unique number from said private key data, and including a pseudo-random number generator responsive to said private key data and a key generator responsive to said pseudo-random number generator and said means to recover said unique number.

6. The key generation system of claim **1** wherein said body part input for generating an information signal comprises optical means for generating an optical information signal and wherein said means for comparing comprises Fourier transform means to obtain a Fourier transform representation of said optical information signal.

7. The key generation system of claim **6** wherein said Fourier transform means comprises optical transform means along a path of said optical information signal and wherein said means for comparing includes (i) a programmable filter responsive to said optical transform means for filtering said Fourier transform representation of said information signal to obtain a filtered Fourier transform representation, (ii) means for programming said filter with said comparison data, and (iii) inverse transform means responsive to said filter to inverse Fourier transform said filtered Fourier transform representation to obtain an inverse transform representation, and including key generating means responsive to said inverse transform means for generating a private key from said private key data.

8. The key generation system of claim **5** wherein said means for comparing comprises Fourier transform means to obtain a Fourier transform representation of said information signal.

9. The key generation system of claim **8** wherein said Fourier transform means comprises transform means along a path of said information signal and wherein said means for comparing includes (i) a programmable filter responsive to said transform means for filtering said Fourier transform representation of said information signal to obtain a filtered Fourier transform representation, (ii) means for programming said filter with said comparison data, and (iii) inverse transform means responsive to said filter to inverse Fourier transform said filtered Fourier transform representation to obtain an inverse transform representation, said key generating means being responsive to said inverse transform means.

10. The key generation system of claim **9** including means to obtain one of said private key and a unique number from which said private key may be derived from said further information signal and wherein said means to generate biometric data from said further information signal comprises means for generating a Fourier transform of said further information signal.

11. The key generation system of claim **10** wherein said means for reading comparison data is also for reading comparison data from a data carrier storing an indication of an intensity of a component of an inverse Fourier transform and wherein said means for comparing is responsive to said data reading means to recover private key data based on said intensity indication as well as based on said inverse transform.

12. A method for generating a private key, comprising the steps of:

generating an information signal bearing biometric information;

reading comparison data from a data carrier, said comparison data comprising private key data encrypted with biometric data; and

comparing said information signal with said comparison data for recovering said private key data form said comparison data.

13. A method for encoding a private key, comprising the steps of:

(a) generating an information signal bearing biometric information from a body part;

(b) obtaining function generation data comprising one of a private key and a unique number from which said private key may be derived;

(c) generating an array based on step (b);

(d) generating biometric data form said information signal;

(e) encrypting said function with said biometric data to generate said comparison data; and

(f) storing said comparison data on said data carrier.

14. The method of claim 12 including the steps of:

(a) generating a further information signal bearing biometric information from said body part;

(b) obtaining function generation data comprising one of said private key and a unique number from which said private key may be derived;

(c) generating a function based on step (b);

(d) generating biometric data from said further information signal;

(e) encrypting said function with said biometric data to generate said comparison data; and

(f) storing said comparison data on said data carrier.

15. The method of claim 14 wherein step (b) comprises obtaining said unique number and including the step of pseudo-randomly generating a private key based on said unique number.

16. The method of claim 12 wherein said step of comparing comprises obtaining a Fourier transform representation of said information signal.

17. The method of claim 16 wherein said step of obtaining a Fourier transform comprises transforming said information signal and wherein said step of comparing includes (i) filtering said Fourier transform representation of said information signal with a filter programmed with said comparison data to obtain a filtered Fourier transform representation, and (ii) inverse Fourier transforming said filtered Fourier transform representation to obtain an inverse transform representation, said step of generating a key utilising said inverse transform.

18. The method of claim 14 wherein said step of comparing comprises obtaining Fourier transform representation of said information signal.

19. The method of claim 18 wherein said step of obtaining a Fourier transform comprises transforming said information signal and wherein said step of comparing includes (i) filtering said Fourier transform representation of said information signal with a filter programmed with said comparison data to obtain a filtered Fourier transform representation, and (ii) inverse Fourier transforming said filtered Fourier transform representation to obtain an inverse transform representation, said step of generating a key utilising said inverse transform.

20. The method of claim 18 including the step of obtaining one of said private key and a unique number from which said private key may be derived from said further information signal and wherein said step of generating biometric data form said further information signal comprises generating a Fourier transform of said further information signal.

21. The method of claim 20 wherein said step of reading comparison data comprises reading an indication of an intensity of a component of an inverse Fourier transform and wherein said step of comparing comprises recovering private key data based on said intensity indication as well as based on said inverse transform.

22. The method of claim 12 including the step of utilising said private key data for decrypting a public key encrypted message.

23. The method of claim 12 including the step of utilising said private key data for accessing a PIN operated device.

24. The method of claim 14 wherein said step of generating a function comprises deriving an array based on said function generation data and, for each element of said array, setting an amplitude of an impulse function based on said each element in order to obtain a weighted impulse function array, and wherein the step of encrypting comprises dividing a Fourier transform representation of said weighted impulse function array by said Fourier transform representation of said further information signal.

25. The method of claim 14 wherein said step of generating a function comprises associating a pattern of impulse functions with said function generation data, and wherein the step of encrypting comprises dividing a Fourier transform representation of said associated pattern of impulse functions by said Fourier transform representation of said further information signal.

26. The method of claim 14 wherein said step of generating a function comprises associating a pattern of impulse functions with said function generation data, deriving an array based on said function generation data and, for each element of said array, setting an amplitude of one impulse function of said pattern of impulse functions based on said each element in order to obtain a weighted impulse function pattern, and wherein the step of encrypting comprises dividing a Fourier transform representation of said weighted impulse function pattern by said Fourier transform representation of said further information signal.

27. A biometric controlled key generation system, comprising:

a body part input for generating an information signal bearing biometric information from a body part;

a programmable filter for filtering a function of said biometric information;

means for reading filter data from a data carrier and for programming said programmable filter with said filter data, said filter data comprising data for use in generating a private key, said private key generating data being encrypted by biometric data; and

means responsive to an output of said filter for recovering said private key generating data.

28. The key generation system of claim 27 including Fourier transform means for obtaining a Fourier transform representation of said biometric information, said function of said biometric information comprising said Fourier transform representation such that said programmable filter is for filtering said Fourier transform representation of said biometric information.

29. The key generation system of claim 28 wherein said body part input is for generating an optical information signal and said Fourier transform means comprises optical Fourier transform means along a path of said optical information signal for obtaining an optical Fourier transform representation of said biometric information, said programmable filter being responsive to said optical transform means for filtering an optical Fourier transform representation of said biometric information to obtain a filtered Fourier transform representation.

30. The key generation system of claim 28 wherein said Fourier transform means comprises digital Fourier transform means for obtaining a digital Fourier transform representation of said biometric information, said programmable filter being responsive to said digital transform means for

filtering a digital Fourier transform representation of said biometric information to obtain a filtered Fourier transform representation.

31. The key generation system of claim **29** including inverse transform means responsive to said programmable filter for obtaining an inverse Fourier transform representation of said filtered Fourier transform representation and including key generating means responsive to said inverse transform means of regenerating a private key from said private key generating data.

32. The key generation system of claim **31** including key generating means for generating a private key from said private key generating data.

33. The key generation system of claim **32** wherein said key generating means comprises means to recover a unique number from said private key generating data, and including a pseudo-random number generator responsive to said means to recover said unique number and a key generator responsive to said pseudo-random number generator and said means to recover said unique number.

34. The key generation system of claim **31** wherein said body part input comprises a fingerprint input for receiving at least one finger of a user.

35. The key generation system of claim **34** wherein said data reading means comprises a card reader.

36. The key generation system of claim **35** wherein said Fourier transform means comprises a Fourier transform lens said programmable filter comprises a programmable spatial light modulator, and said inverse transform means comprises a lens.

37. The key generation system of claim **31** wherein said data filter reading means includes means for reading data form a data carrier storing an indication of an intensity and wherein said unique number generator is responsive to said data reading means to generate a unique number from said intensity indication as well as from said inverse transform.

38. The key generation system of claim **32**, adapted for use as a public key cryptographic system, comprising user controlled selection means and wherein said key generating means is responsive to said selection means for selectively generating one of said private key for decrypting a message and a public key for encrypting a message.

39. The key generation system of claim **38** including a public key decryption system for storing an encrypted message and, responsive to any private key generated by said key generating means, for attempting to decrypt said encrypted message with said private key.

40. A biometric controlled private key encoding system, comprising:

a body part input for generating an information signal bearing biometric information from a body part;

means to generate a function based on one of a private key or a unique number from which said private key may be derived;

means to generate biometric data from said information signal;

means to encrypt said function with said biometric data to generate filter data for a programmable filter; and

means for storing said filter data on a data carrier.

41. The key generation system of claim **40** wherein said means to generate biometric data from said information signal comprises means for generating a Fourier transform representation of said biometric information.

42. The key generation system of claim **41** wherein said means to generate a function comprises means to generate a Fourier transform representation based on one of said private key and said unique number and wherein said means to encrypt said function comprises means to divide said Fourier transform representation based on one of said private key and said unique number by said Fourier transform representation of said biometric information to obtain said filter data.

43. A method for generating a private key, comprising the steps of:

generating an information signal bearing biometric information;

reading filter data form a data carrier, said filter data comprising data for use in generating a private key encrypted with biometric data;

programming a programmable filter with said filter data; and

recovering private key generating data form said filter data by filtering a function of said biometric information with said programmed filter.

44. The method of claim **43** including the step of obtaining a Fourier transform representation of said biometric information, said Fourier transform representation of said biometric information comprising said function of said biometric information.

45. The method of claim **44** wherein the step of recovering private key generating data includes the step of inverse Fourier transforming data filtered by said filtering step.

46. The method of claim **45** wherein the step of recovering private key generating data includes the step of reading an indication of an intensity indication from said data carrier.

47. The method of claim **43** including the step of utilising said private key generating data for decrypting a public key encrypted message.

48. The method of claim **43** including the step of utilising said private key generating data for accessing a PIN operated device.

49. A method for encoding a private key, compromising the steps of:

(a) generating an information signal bearing biometric information from a body part;

(b) generating function generation data comprising one of a private key or a unique number from which said private key may be derived;

(c) obtaining a function based on said function generation data;

(d) generating biometric data from said information signal;

(e) encrypting said function with said biometric data to generate filter data for a programmable filter; and

(f) storing said filter data on a data carrier.

50. The method of claim **49** wherein said step of generating biometric data comprises obtaining a Fourier transform representation of said biometric information.

51. The method of claim **50** wherein the step of obtaining a function comprises obtaining a Fourier transform representation based on said function generation data and wherein the step of encrypting said function comprises dividing said Fourier transform representation of said function by said Fourier transform representation of said biometric information to obtain said filter data.

52. The method of claim **51** wherein said step of obtaining a Fourier transform representation based on said function generation data comprises generating an array from said function generation data, choosing a set of impulse functions based on said array, and obtaining a Fourier transform from said set.

53. The method of claim **52** wherein the step of choosing a set of impulse functions comprises, for each element of said array, setting an amplitude of an impulse function based on said each element in order to obtain a set of weighted impulse functions.

54. The method of claim **50** wherein said step of choosing a set of impulse functions comprises associating a pattern of impulse functions with each element of said array of function generation data.

55. The method of claim **50** wherein step (b) comprises obtaining said unique number and including the step of pseudo-randomly generating a private key based on said unique number.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,680,460

DATED : OCTOBER 21, 1997

INVENTOR(S) : TOMKO ET AL.

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Claim 12, column 12, line 64, cancel "form" and insert —from—.

Claim 14, column 13, line 8, cancel "form" and insert —from—.

Claim 20, column 13, line 60, cancel "form" and insert —from—.

Claim 31, column 15, line 9, cancel "of regenerating" and insert —for generating—.

Claim 37, column 15, line 34, cancel "form" and insert —from—.

Claim 43, column 16, line 15, cancel "form" and insert —from—.

Claim 43, column 16, line 21, cancel "form" and insert —from—.

Claim 49, column 16, line 43, cancel "compromising" and insert —comprising—.

Signed and Sealed this

Twenty-eighth Day of July, 1998

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks