# Fourier domain asymmetric cryptosystem for privacy protected multimodal biometric security

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#### ABSTRACT

We propose a Fourier domain asymmetric cryptosystem for multimodal biometric security. One modality of biometrics (such as face) is used as the plaintext, which is encrypted by another modality of biometrics (such as fingerprint). A private key is synthesized from the encrypted biometric signature by complex spatial Fourier processing. The encrypted biometric signature is further encrypted by other biometric modalities, and the corresponding private keys are synthesized. The resulting biometric signature is privacy protected since the encryption keys are provided by the human, and hence those are private keys. Moreover, the decryption keys are synthesized using those private encryption keys. The encrypted signatures are decrypted using the synthesized private keys and inverse complex spatial Fourier processing. Computer simulations demonstrate the feasibility of the technique proposed.

Keywords: Biometric pattern recognition, privacy protection, multimodal biometrics, asymmetric cryptosystem

### 1. BACKGROUND OF CRYPTOGRAPHY

Secure communication and sharing of secret information often require special expensive channels. Alternatively, the information may be encrypted and may be exchanged between the users through public channels. In old days, the secret keys used to be distributed through secure channels, generally by registered post or courier, which are slow and costly. This is known as symmetric key cryptography. The invention of public key cryptography by Diffie and Hellman,<sup>1</sup> and independtly by Merkle<sup>2</sup> have radically changed the approaches of key distribution in cryptography. A public key cryptosystem<sup>1</sup> has two keys, one for encryption and one for decryption. The two keys effect inverse operations and hence are related, but the decryption key can't be easily derived from the encryption key.<sup>1</sup> The public key cryptography uses different keys for encryption and decryption, and hence is known as asymmetric key cryptography. The field has been continually enriched by the research works of Rivest et al.<sup>3</sup> Merkle and Hellman<sup>4</sup> and McEliece.<sup>5</sup> The Rivest-Shamir-Adleman public key scheme or the widely known as RSA scheme rely on the fact that it is easy to generate two large primes and multiply them together, but it is very difficult to factor the result.<sup>3</sup> Merkel and Hellman have used the trapdoor knapsack problems which are also very difficult to solve.<sup>4</sup> McEliece's cryptosystem is based on algebraic coding theory where a random Goppa code is chosen to synthesize the encryption key by permutation, the secret decryption key being the permutation and choice of Goppa code. In all these seminal cryptosystems, the secret decryption keys are required to be created from the public encryption keys following some secret mathematical rules or puzzles.<sup>6</sup>

#### 2. MOTIVATION FOR BIOMETRICS AND PRIVACY PROTECTION

Biometrics refer to the physiological human traits such as face, fingerprint, iris, palm prints etc. and the behavioral human traits such as gait, voice, walking style, gesture, typing rhythm etc. Biometric signatures are unique to individuals and hence are reliable for identifying human beings. Biometric authentication is gaining more acceptance day by day in a variety of applications in governmental programs as well as in personal verication

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problems.<sup>7,8</sup> Biometrics can provide a way to synthesize keys for asymmetric encryption. Biometric data is also more difficult to be stolen or attacked making the encryption process inherently more secure and robust than storing text keys.<sup>9</sup> Moreover, biometric keys being more secure, they also provide a way for personal identity verification because only the individual with matching biological traits would be able to produce the correct biometric key.<sup>10</sup>

A biometric template is a representation of several unique characteristics of individuals, and hence it contains sensitive personal and private information. Biometric identification requires a verifier to search for matches in the entire database of biometric signatures of the whole population. This can naturally open a possible security threat that the verifier can steal the biometric templates from the database. A malicious verifier can acquire the biometric templates and try severe impersonation attacks. Thus privacy protection is very essential in biometric authentication process because the biometric template data may be misused by dishonest verifiers.<sup>11,12</sup> Security and privacy are two essential requirements of biometric systems, but they mutually hinder each other. Biometric encryption has been an easy way for privacy protection and surmounting security threats,<sup>13</sup> although there are several other methods available for securing the privacy information.<sup>12</sup>

In this paper, it is tried to utilize the principles of asymmetric key cryptography to encrypt and decrypt biometric signatures using Fourier domain cryptography popularly known as double random phase encoding<sup>14</sup> and phase truncated Fourier transform.<sup>17</sup> The encrypted biometric signatures are inherently privacy protected by the respective asymmetric keys derived from multimodal biometric traits of the humans.

#### 3. THE PROPOSED ASYMMETRIC CRYPTOSYSTEM

The double random phase encoding cryptographic protocol relies on encryption of the plaintext using two random phase functions by two Fourier transformations.<sup>14–16</sup> The plaintext is multiplied by a random phase function (first private key) and Fourier transformed which is again multiplied by a second random phase function (second private key) and inverse Fourier transformed. Since this algorithm utilizes two random phase functions for encryption, it is called double random phase encoding (DRPE). If we have an information specified by a spatial function f(x, y), and have two independent white sequences  $r_1(x, y)$  and  $r_2(x, y)$ , the encrypted function g(x, y)after DRPE will be given by

$$g(x,y) = [f(x,y)\exp\{j2\pi r_1(x,y)\}] \circledast \exp\{j2\pi r_2(x,y)\}$$
(1)



Figure 1. Double random phase encoding: (a) encryption algorithm, and (b) decryption algorithm.

where x, y are the space coordinates,  $j = \sqrt{-1}$  and  $\circledast$  is a convolution operation. The flow diagrams of encryption and decryption algorithms based on DRPE is given in Fig.1 where FT denotes a Fourier transform operator.

We propose an asymmetric cryptosystem that utilizes one modality of biometric signature as the plain text image, and another modality of the biometric signature is used as a private encryption key. The second biometric modality image is also encrypted using DRPE technique. The plain text image is multiplied by the complex exponential function of the DRPE encrypted second biometric signature, and the product is Fourier transformed. The phase part of the Fourier transform is extracted and is preserved as a private decryption key.<sup>17</sup> The amplitude part of the Fourier transform is utilized for further encryption by a third biometric signature. The product of the amplitude part of the Fourier transform and the exponential function of the DRPE encrypted third biometric



(a)



Figure 2. The proposed asymmetric cryptosystem: (a) encryption algorithm, and (b) decryption algorithm.

key is inverse Fourier transformed. Then, again the phase part of it is extracted and is preserved as a second private decryption key. The amplitude part of the Fourier transform is the encrypted privacy protected biometric signtaure.

Let  $b_1$  be the first biometric trait image of a human (such as face), and  $b_{E2}$ ,  $b_{E3}$  be his/her other two biometric trait images (such as, fingerprint and iris) but are encrypted by DRPE. If PT be a phase truncation operator and PR be a phase reservation operation, we can express our cryptosystem using the flow diagram of Fig.2(a). The two private phase keys PK<sub>1</sub> and PK<sub>2</sub> are extracted by the PR operation. The final encrypted image PPBS represents the privacy protected biometric signature.

The encrypted biometric signature PPBS can be decrypted using the synthesized private phase keys  $PK_1$  and  $PK_2$  as shown in the flow diagram of Fig.2(b). These encrypted privacy protected biometric signatures can be preserved in the database. These data can be used for authentication by cross-correlation operation.<sup>18</sup>

## 4. SIMULATION RESULTS

The feasibility of the proposed cryptosystem is tested by implementing the algorithm on image data of human face and fingerprints. To check our algorithm, we have used a few face images from the Yale Face Database B and have associated a few fingerprint images from the Bologna fingerprint data base. The face image is used as a plain text image, and the two fingerprint images are encrypted by DRPE method and the encrypted versions

of the fingerprint images are utilized as encryption keys to encrypt the face image. The fingerprint images of a human subject's right and left thumbs, and a human subject's face are respectively shown in Fig.3(a), 3(e) and 3(i) respectively, which are the plain images in our simulation experiment. The corresponding cipher images of



Figure 3. Results: (a) fingerprint of right thumb, (e) fingerprint of left thumb, (i) face of the human subject; (b), (f) cipher images of the fingerprints by DRPE, (j) final privacy protected cipher image of the human face; (c), (g), (k) histograms of the plain images; (d), (h), (l) histograms of the cipher images

the fingerprint images by DRPE are shown in Fig.3(b) and (f). These encrypted images of Fig.3(b) and (f) are utilized to produce the final privacy protected biometric signature PPBS by our proposed encryption algorithm and is shown in Fig.3(j). The histograms of the plain images are shown in Fig.3(c), (g) and (k) respectively. The histograms of the cipher images are shown in Fig.3(d), (h) and (l) respectively. It is noticed from the results that there remains significant differences between the histograms of the plain images and that of the cipher images. According to the theory of classical cryptology it is good because this can be considered as diffusion, which diffuses the statistical characteristics of original image to the whole space. In addition, we also find that the cipher image of different original images have similar histograms after encrypted with independent encryption keys. This can be considered as confusion in the classical cryptology. It is difficult for attackers to obtain useful information from the statistical characteristics, thus it can provide considerable capacity of resisting statistical cryptanalysis.

The final privacy protected biometric signature can be decrypted by phase truncated Fourier transform algorithm of Fig.2 using appropriate private phase keys  $PK_1$  and  $PK_2$ . This result is shown in Fig.4. With correct phase keys, the original plain image of the human subject is extracted as shown in Fig.4. When one of the phase keys, here the second phase key  $PK_2$ , is put incorrect, the algorithm produces an incorrect extraction which is a random image instead of the original face image as shown in Fig.4(b).

![](_page_4_Figure_0.jpeg)

Figure 4. Decryption result: (a) decrypted image with correct phase keys, (b) no decryption with a false key.

The final encrypted PPBS can be used for authentication using cross-correlation.<sup>18</sup> A high correlation peak authenticates the untampered cipher image and confirms no man-in-the-middle attacks. The height of the correlation peak determines whether it is a correct recognition or otherwise. Figure 5 shows the three-dimensional

![](_page_4_Figure_3.jpeg)

Figure 5. Plots of cross-correlation: (a) authentication of correct cipher biometric signature (correlation peak height=0.99), (b) biometric rejection, no authentication (correlation peak height=0.2).

plots of the cross-correlation functions. A successful biometric recognition is confirmed by the high correlation peak of Fig.5(a) which is 0.99. When the PPBS of Fig.3(j) is cross-correlated with a false signature, such as that of Fig.4(b), a very low correlation peak is produced as shown in Fig.5(b) (which is equal to 0.2), and it signifies biometric rejection. All the implementation of the algorithms have been carried out using GNU Octave.<sup>19</sup>

## 5. CONCLUSION

An asymmetric cryptosystem is proposed for privacy protection in biometric pattern recognition. The face biometrics is encrypted by fingerprint biometrics and double random phase encoding. Two private phase keys are generated by phase truncated Fourier transform. The encrypted final biometric image is privacy protected. The encrypted biometric signature is decrypted by using the synthesized two private phase keys. The encryption keys and the decryption keys are different. Authentication of the encrypted biometric signature is also carried out by cross-correlation operation. Simulation results verify the feasibility of the proposed cryptosystem.

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