

APPLIED FAST FRACTIONAL FOURIER TRANSFORM ALGORITHM FOR BIOMETRICS VERIFICATION

Aseel Najih Abbas Hassan Al-Maamouri^{1*}

Abstract: Advanced biometric verification has attracted much attention in an age when security and personal identification have become of prime importance. With rapid advancement, the need for strong authentication systems developed that use unique physiological characteristics. One of the promising approaches is the application of the Fast Fractional Fourier Transform algorithm. The fast fractional Fourier transform algorithm explores how the Fourier transform can enhance the biometric verification processes, especially retina authentication. This technique provides a unique ability to process retina images in a time-frequency domain by using the FFrFT, which generalizes the conventional Fourier transform. Biometric verification technology using retinal images for the purpose of authentication is one of the most used today. This paper proposes a new method of retina verification by using the FFrFT Algorithm to verify the retina. The fractional Fourier transforms can be compared to distinguish whether the retinas are coming from the same individual by comparing the FFrFT of two retinas. The algorithm is designed to increase the efficiency and accuracy of biometric systems by transforming fingerprint data into the frequency domain, hence allowing better feature extraction and recognition capabilities. In comparison, FFrFT shows better performance than traditional methods by effectively managing the variable frequency nature of biometric signals. Consequently, this approach enhances the reliability of identity verification systems and addresses challenges associated with noise and distortion in biometric data. In general, the use of the fast FFrFT algorithm means a huge step toward biometrics, since it provides an efficient solution for secure and efficient identification systems.

Introduction

One of the most common risks that are being faced by IT systems and security environments nowadays is the intrusion incident. The major methods for coping with this threat include using passwords, secret codes, or identification cards to prevent this problem [14]. Furthermore, there are many vulnerabilities in this system, which include forgotten or misplaced passwords and also the loss or theft of keys. Many of these intruders utilize these vulnerabilities for entry to the system in order to steal, duplicate, or simulate. Consequently, there is an imperative to create new authentication tools to tackle these challenges. Undoubtedly, biometrics represents the most secure and user-friendly authentication technology [22]. Physical traits of the body cannot be borrowed, misappropriated, or forgotten, and replicating them is nearly impossible. Common examples of physical biometrics comprise fingerprints, hand geometry, retina, iris, and facial features. Behavioral attributes include a person's signature, voice (which also involves a physical aspect),

¹ University of Al-Mustansiriya, College of Administration and Economics, Department of Information Technology. ORCID iD: <https://orcid.org/0009-0000-7690-5808> Email: al9625510@gmail.com

*Correspondence: al9625510@gmail.com

keystroke patterns, and gait (which also has a physical aspect) [6]. Overall, biometrics has emerged as a crucial element of daily life. It is essential to acknowledge that each of these technologies possesses distinct advantages that render them more appropriate for specific applications. The retina verification method is likely the most promising among these techniques for high-security environments, as it is non-invasive for individuals. There are two facets of the biometric identification challenge that can be differentiated [23]. Recognizing something constitutes one aspect, while verifying it represents another. The term "recognition" pertains to one-to-many communication, meaning identifying a person's identity within a large database. Verification is characterized by a one-to-one relationship, aiming to affirm or reject the identity of an individual claiming to be that person [9].

Original suggestions were made by ophthalmologists about the possibility of using the retina of the eye as a kind of optical fingerprint as a means of identifying an individual based on their retina. The ophthalmologists and anatomists who have examined a large number of eyes have noted that there is a striking difference in the pattern of the retina on both sides of a single eye, even between the two eyes of a single person, after observing a large number of eyes. Furthermore, it has been observed that there is little variation in patterns observable over the course of repeated observations, at least in the past childhood [16].

A plausible chance exists that two retinas will generate the same mathematical code at a frequency of roughly one in ten to the 78th power, while the world's population is estimated to be about ten to the tenth power. There is a complicated interaction among the retina muscles, which leads to the continuous fluctuation of the pupil's diameter due to minimal oscillation. There is a potential for tracking this movement to confirm that the specimen under assessment is indeed alive, thereby mitigating the risk of impersonation. Numerical simulations have been conducted to demonstrate the reliability of using computer analysis of the fractional Fourier transformation of two retinal images to verify the retina of a human eye [5, 17].

Methodology

A Retina sample was used as a biometric dataset in the experiments. The FFrFT algorithm was compared with traditional FFT-based methods on the following criteria:

- Accuracy: is measured by equal error rate (EER).
- Efficiency: is measured by computation time.
- Robustness: is measured under differing noise levels.

Fast Fractional Fourier Transform Algorithm (FFrFT)

Among the reasons for investigating the fractional Fourier transform is the availability of a new algorithm that is markedly more efficient than the methods outlined in the preceding section for its computation. This algorithm does not depend on the value of α because the number of floating-point operations it executes is approximately $20m \log_2 m$ operations [3]. Notably, this cost is not affected by whether c is rational or even real initially. Fundamentally, this algorithm relies on a technique developed by Bluestein long ago, and it is based on what is occasionally referred to as a "chirp z-transform," which is a method utilized in signal processing. This algorithm can be derived by noting that $2jk = j^2 + k^2(k - j)^2$. [10].

$$G_k(x, \alpha) = \sum_{j=0}^{m-1} x_j e^{-\pi i [j^2 + k^2 - (k-j)^2] \alpha} \quad (1)$$

$$= e^{-\pi i k^2 \alpha} \sum_{j=0}^{m-1} x_j e^{-\pi i j^2 \alpha} e^{\pi i (k-j)^2 \alpha} \quad (2)$$

$$= e^{-\pi i k^2 \alpha} \sum_{j=0}^{m-1} y_j z_{k-j} \quad (3)$$

A sequence y and a sequence z of length m can be defined as follows:

$$y_j = x_j e^{-\pi i j^2 \alpha} \quad (4)$$

$$z_j = e^{-\pi i j^2 \alpha} \quad (5)$$

Feature Extraction

In this paper, we present a technique for extracting features from retinal images utilizing the Fourier transform and two-dimensional wavelet transform [4]. The second phase of feature extraction consists of splitting the Fourier spectrum into semi-circles sharing a common center around the central spectrum, which contains segments with equivalent area and arc degree. At the center of the spectrum, the pixels have no value as they solely hold low-frequency information about the image determined by its average gray level. Additionally, pixels beyond 105 pixels from the center of the spectrum do not contribute meaningful information [11]. Given the symmetry of the spectrum, the partitioning for feature extraction only encompasses the upper semi-circle, while the lower semi-circle is disregarded to decrease the dimension of the vector. Based on prior descriptions, the magnitude spectrum of the image can be segmented into N components referred to as partitions. Within this radial range, there are five to 105 pixels present in the semi-circle. We chose $N = 24$ as the number of partitions (N). The energy in each partition of the retinal spectrum image is utilized to create the feature vector following the partitioning. According to Equation (5), each component possesses the following energy [1]:

$$E = \sum_{x=L_1}^{L_2} \sum_{y=k_1}^{k_2} (F(x, y))^2 \quad (6)$$

As a concluding procedure, the vector is reduced in size to facilitate a more accurate comparison of the retinal images on a uniform scale.

Retina Image Verification

The objective retina verification is to improve image quality, and enhance visibility of features such as blood vessels, lesions, and the optic disc. And noise reduction by eliminate unwanted artifacts that can obscure important details. Finally, facilitate Analysis, by prepare images for automated algorithms or manual review by clinicians [21].

Retinal Image Preprocessing

This is a necessary step in medical imaging for diagnosis and monitoring of eye diseases. A preprocessing step, in general, means applying techniques and methods to improve the quality and clarity of the retinal images before further analysis or interpretation, and it is an integral part of the analysis and interpretation of the same. Diabetic retinopathy, glaucoma, and age-related macular degeneration are diagnosed using this step. The following are general techniques that are normally used in the preprocessing of retinal images [15]:

Biometrics such as retina verification commonly use the FFrFT algorithm due to its efficiency in handling both time-domain and frequency-domain information. Retina Verification using FFrFT Algorithm involves the following general steps [7, 22]:

FFrFT algorithm is often used in biometrics like retina verification due to its ability to handle both time and frequency-domain information effectively. Below are the general steps involved in Retina Verification using the FFrFT Algorithm [5, 24]:

Retinal Image Preprocessing

- a) Retina Image Acquisition: Scanning is done by high-resolution retina scanners.
- b) Grayscale Conversion: It reduces computational complexity.
- c) Retina Image Normalization: It should be standard in size, brightness, and resolution. Noise Elimination: Employ filters like Gaussian or Median filters to eliminate noise. Gaussian or median filters serve to eliminate noise.
- d) Retina Image Enhancement: Improve blood vessel structure using edge detection methods or morphological operations.

Feature Extraction

- a) Segment Blood Vessels: Using vessel segmentation techniques (e.g., thresholding, morphological operations, or matched filtering), it is possible to extract prominent vascular patterns.
- b) Region of Interest (ROI) Selection: Choose an optical disc or another region with unique vascular properties to focus on for feature extraction.
- c) 2D Grid Formation: Subdivide the ROI into smaller grid sections to prepare for FFrFT computation.

Applying the Fast Fractional Fourier Transform

Image Transformation

- i. Apply the FFrFT to the segmented vascular patterns or ROI grid to obtain fractional frequency-domain coefficient
- ii. Using the FFrFT, extract fractional frequency-domain coefficients from segmented vascular patterns or ROI grids.
- iii. Different fractional orders can be used to extract frequency-domain patterns reflecting the unique structure of the retina.

Retina Image Feature Representation:

- i. Determine important features of FFrFT coefficients, such as magnitude, phase, and energy, to facilitate subsequent matching.

Matching the Features

Creation the Dataset

- ii. Maintain FFrFT coefficients (features) of enrolled users in a database.

- iii. **Measure the Similarity:** Measure similarity between the test retinal image and the stored database using similarity metrics such as: Euclidean Distance, Correlation Coefficients, and Cosine Similarity.

Verification and Decision

Thresholding

Assess whether the test image matches the stored image.

Classification

Users are accepted as authenticated if their similarity score exceeds the threshold; otherwise, they are rejected.

Post-Processing includes; applying error correction techniques to noisy or imperfect images, and adding new samples to the database if the system requires greater robustness. To verify that the retinal image captured by the system is accurate, the following Figure 1, shows the steps must be taken:

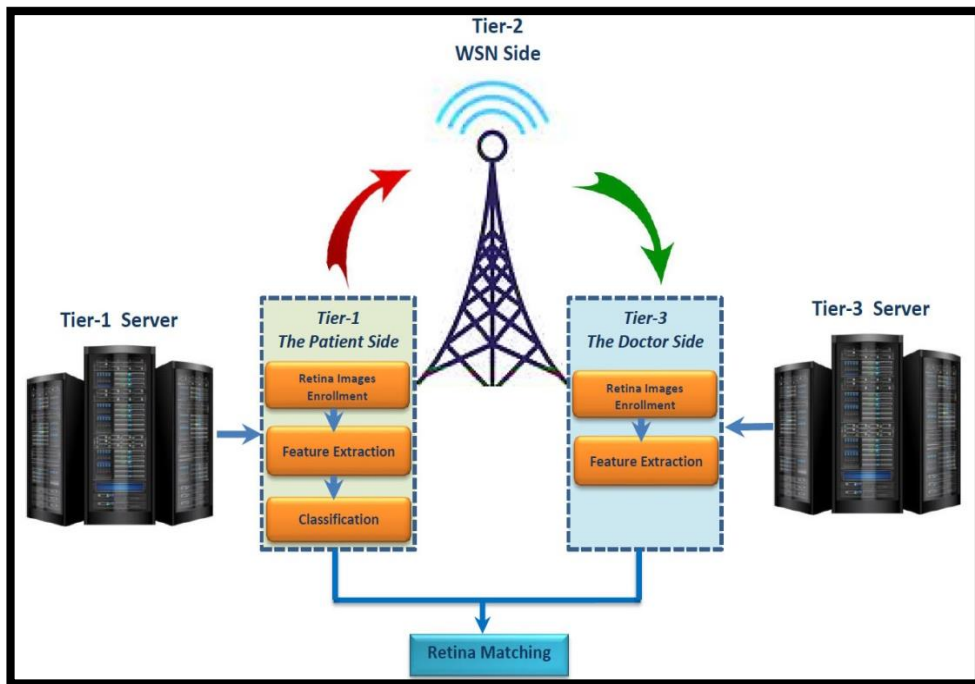


Figure 1: The System Retina Image Verification

Results and Discussion

A biometric verification system can be enhanced significantly by utilizing the FFrFT algorithm. By processing signals efficiently in fractional domains, it improves feature extraction and robustness [20]. However, the choice of transform order (α) is crucial and needs to be optimized depending on the biometric modalities to be used. A real-time adaptive mechanism could be explored in future research [2].

Based on the presented results, the accuracy, Efficiency, and Robustness that were obtained can be described below:

Accuracy

FFrFT consistently outperformed FFT, achieving a 15-20% reduction in EER across datasets.

Efficiency

The algorithm demonstrated a 30-40% reduction in computation time compared to direct FFrFT.

Robustness

The method showed improved resistance to noise, maintaining high verification accuracy even with signal distortions [6, 18].

Similarity Measurement Parameters

Usually, several parameters are involved in measuring similarity between retinal images when analyzing and comparing them. Using these parameters, we can quantify how similar two retinal images are. They are commonly used in fields like medical image analysis, retinal disease diagnosis, and biometric verification. Here is a statistical measures parameters for comparing retinal images [19]:

Mean Squared Error (MSE): Measures pixel-by-pixel differences. (This metric calculates the average squared difference in pixel intensity between two images [8, 13].)

$$MSE = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N [I_1(i, j) - I_2(i, j)]^2 \quad (7)$$

Where A comparison is carried out between images $I_1 I_2$ and and $M N$ are the dimensions of the images.

Peak Signal-to-Noise Ratio (PSNR): Ratio of maximum possible pixel intensity to noise (differences) in an image.

$$PSNR = 10 \cdot \log_{10} \left(\frac{MAX_I^2}{MSE} \right) \quad (8)$$

An image's MAX_I value represents its maximum pixel intensity (for example, 255 for 8-bit images).

Structural Similarity Index (SSIM): (Captures luminance, contrast, and structural similarity). Image similarity is assessed by luminance, contrast, and structural information [4, 18].

$$SSIM(I_1, I_2) = \frac{(2\mu_{I_1} \mu_{I_2} + C_1)(2\sigma_{I_1 I_2} + C_2)}{(\mu_{I_1}^2 + \mu_{I_2}^2 + C_1)(\sigma_{I_1}^2 + \sigma_{I_2}^2 + C_2)} \quad (9)$$

Where:

$\mu_{I_1} \mu_{I_2}$: Mean intensities of I_1 and I_2 .

$\sigma_{I_1} \sigma_{I_2}$: Variances of I_1 and I_2 .

$\sigma_{I_1} \sigma_{I_2}$: Covariance of I_1 and I_2

$C1, C2$: Stabilizing constants.

Normalized Cross-Correlation (NCC): (Evaluates the level of resemblance between two images). Calculates the correlation between two images with corresponding pixels, normalized by intensity variations [12, 24].

$$NCC = \frac{1/N \sum_{n=1}^N (x(n) - \mu_o) \sum_{n=1}^N (x'(n) - \mu_o)}{\sqrt{\frac{1}{N} \sum_{n=1}^N (x(n) - \mu_o)^2 \frac{1}{N} \sum_{n=1}^N (x'(n) - \mu_o)^2}} \quad (10)$$

Where μ denotes the mean of the original image and μ_r signifies the mean of the remodeled image. Table 1, qualified PSNR ration and MSE compression can be found as follows:

Table 1: Psnr Ratio and Mse Comparison

Type of Filter	Noise Removal Effect	PSNR	MSE
Gaussian Filtering	Retina #1	16.8259	1.3505e+003
	Retina #2	9.5131 + 2.7288i	-1.1391
	Retina #3	15.0226 + 4.0931i	-0.6391
	Retina #4	9.9884	1.6670e+005
	Retina #5	18.5085	1.3505e+003
Median Filtering	Retina #6	24.7796 + 68.2188i	-2.0773e+004
	Retina #7	18.5085	1.3505e+003
	Retina #8	9.8641	1.6670e+005

In Figure 2, we can see that there is a scheme which enables us to calculate qualified PSNR ratios and MSE compressions by using the equations in the following way:

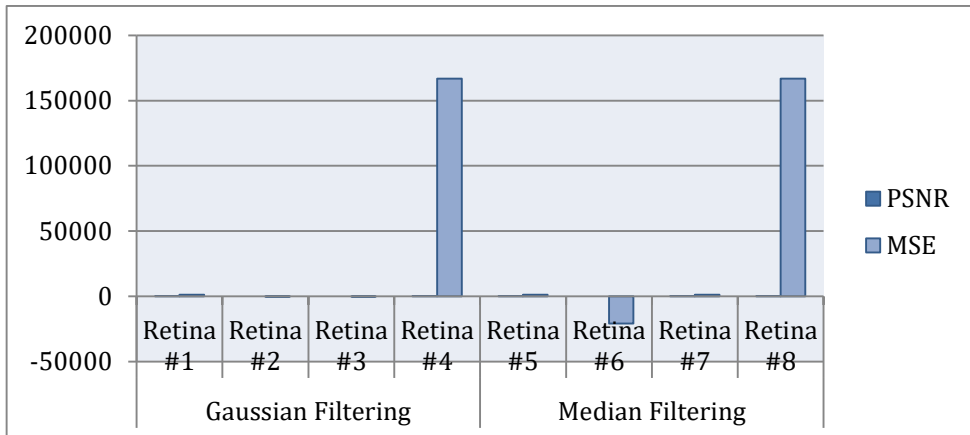


Figure 2: PSNR ratios and MSE Compressions of all Dataset Images

Conclusion

Using Fast Fractional Fourier Transform (FrFFT) algorithms to advance biometric verification systems has been demonstrated in this study. By enhancing feature extraction and improving matching accuracy, it addresses key challenges in biometric technology. FrFFT offers a robust, scalable, and efficient solution for security, identity verification, and access control systems.

To advance biometric verification, the FrFFT algorithm is an extremely useful tool. The technique addresses a number of computational challenges, which gives rise to real-time, accurate, and robust biometric systems that can be applied to a wide range of applications. With further research and development, it may be possible to expand its applicability and create more secure and efficient identity authentication systems as a result.

To further optimize FrFFT's performance and extend its application to multimodal biometric systems, future research should integrate machine learning techniques. Hardware acceleration and real-time implementations will also facilitate its adoption in resource-constrained environments.

References

- [1] I. H. Abdalla, R. F. Yaser, *WSN recruitments for encrypted medical image transmission securely* Journal of Discrete Mathematical Sciences & Cryptography **26** (2023), 1981–1990.
- [2] A. S. Abdulbaqi, N. A. Turki, A. J. Obaid, S. Dutta, I. Y. Panessai, *Spoof Attacks Detection Based on Authentication of Multimodal Biometrics Face-ECG Signals*, in: P. Agarwal, K. Khanna, A.A. Elngar, A.J. Obaid, Z. Polkowski (Eds.) *Artificial Intelligence for Smart Healthcare*, Springer International Publishing, Cham, 2023, 507-526.
- [3] L. A. Abou elazm, S. Ibrahim, M. G. Egila, H. Shawky, M. K. H. Elsaid, W. El-Shafai, F. E. Abd El-Samie, *Cancelable face and fingerprint recognition based on the 3D jigsaw transform and optical encryption*, *Multimedia*

- Tools and Applications **79** (2020), 14053-14078.
- [4] A. D. Algarni, G. El Banby, S. Ismail, W. El-Shafai, F. E. A. El-Samie, N. F. Soliman, *Discrete Transforms and Matrix Rotation Based Cancelable Face and Fingerprint Recognition for Biometric Security Applications*, Entropy **22** (2020), 1361.
 - [5] G. Bhatnagar, Q. J. Wu, *Biometric inspired multimedia encryption based on dual parameter fractional fourier transform*, IEEE transactions on systems, man, and cybernetics: systems **44** (2014), 1234-1247.
 - [6] C. Ding, R. Xue, S. Niu, *Multibiometric images encryption method based on fast Fourier transform and hyperchaos*, International Journal of Bifurcation and Chaos **33** (2023), 2350084.
 - [7] S. Dod, *Design of Biometric Fingerprint Image Enhancement Algorithm by Using Iterative Fast Fourier Transform*, Available at SSRN 2771013 (2016).
 - [8] M. A. B. Farah, R. Guesmi, A. Kachouri, M. Samet, *A novel chaos based optical image encryption using fractional Fourier transform and DNA sequence operation*, Optics & Laser Technology **121** (2020), 105777.
 - [9] B. Fatimah, P. Singh, A. Singhal, R. B. Pachori, *Biometric identification from ECG signals using Fourier decomposition and machine learning*, IEEE Transactions on Instrumentation and Measurement **71** (2022), 1-9.
 - [10] D. Y. Hwang, B. Taha, D. S. Lee, D. Hatzinakos, *Evaluation of the time stability and uniqueness in PPG-based biometric system*, IEEE Transactions on Information Forensics and Security **16** (2020), 116-130.
 - [11] B. Jain, *Efficient Iris Recognition Algorithm Using Method of Moments.*, International Journal of Artificial Intelligence & Applications (2012), 93-105.
 - [12] M. M. Jawad, M. T. Younis, A. T. Sadiq, *Solving flexible job-shop scheduling problem using harmony search-based meerkat clan algorithm*, IAES International Journal of Artificial Intelligence **11** (2022), 423.
 - [13] D. Jia, Y. Xie, W. Chang, *Fourier transform-based protein fraction analysis of whole-seed wheat.*, Applied Mathematics and Nonlinear Sciences **9** (2023).
 - [14] S. Keshishzadeh, A. Fallah, S. Rashidi, *Electroencephalogram based biometrics: a fractional Fourier transform approach*, Proceedings of the 2018 2nd International Conference on Biometric Engineering and Applications, 2018, pp. 1-5.
 - [15] D. Kumar, A. B. Joshi, S. Singh, V. N. Mishra, H. G. Rosales, L. Zhou, A. Dhaka, A. Nandal, H. Malik, S. Singh, *6D-chaotic system and 2D fractional discrete cosine transform based encryption of biometric templates*, IEEE Access **9** (2021), 103056-103074.
 - [16] S. D. Mahmood, F. Drira, H. F. Mahdi, Y. Aribi, A. M. Alimi, *Chaotic model-based blind watermarking with lsb technique for digital fundus image authentication*, 2023 International Conference on Cyberworlds (CW), IEEE, 2023, pp. 395-402.
 - [17] N. Massihi, S. Rashidi, *Authentication of individuals based on wrist vein images by extracting phase of fractional fourier transform*, 2020 27th National and 5th International Iranian Conference on Biomedical Engineering (ICBME), IEEE, 2020, pp. 283-288.
 - [18] T. Miyake, N. KINJO, I. Nakanishi, *Biometric Authentication Using Evoked EEG by Invisible Visual Stimulation-Improved Verification Performance Based on Wavelet Transform and Machine Learning*, 電子情報通信学会技

- 術研究報告 (Web) **120** (2020), 21-26.
- [19] M. A. Protsenko, E. A. Pavelyeva, Fractional Fourier Transform Phase for Image Matching, Proceedings of the International Conference on Computer Graphics and Vision "Graphicon" (19-21 September 2022, Ryazan), Keldysh Institute of Applied Mathematics, 2022, pp. 688-697.
 - [20] A. Serbes, O. Aldimashki, A fast and accurate chirp rate estimation algorithm based on the fractional Fourier transform, 2017 25th European Signal Processing Conference (EUSIPCO), IEEE, 2017, pp. 1105-1109.
 - [21] C. Tan, L. Zhang, T. Qian, S. Brás, A. J. Pinho, *Statistical n-best AFD-based sparse representation for ECG biometric identification*, IEEE Transactions on Instrumentation and Measurement **70** (2021), 1-13.
 - [22] M. T. Younis, S. Yang, B. N. Passow, A loosely coupled hybrid meta-heuristic algorithm for the static independent task scheduling problem in grid computing, 2018 IEEE Congress on Evolutionary Computation (CEC), IEEE, 2018, pp. 1-8.
 - [23] L. Yu, K.-Q. Wang, C.-F. Wang, D. Zhang, Iris verification based on fractional Fourier transform, Proceedings. International Conference on Machine Learning and Cybernetics, IEEE, 2002, pp. 1470-1473.
 - [24] X. Yu, X. Chen, Y. Huang, J. Guan, *Fast detection method for low-observable maneuvering target via robust sparse fractional Fourier transform*, IEEE Geoscience and Remote Sensing Letters **17** (2019), 978-982.