UDC 51
DOI: 10.15587/1729-4061.2022.266259

FEATURES EXTRACTION OF FINGERPRINTS BASED ON HYBRID PARTICLE SWARM OPTIMIZATION AND BAT ALGORITHMS

Ahmed Luay Ahmed
Corresponding author
Lecturer, Master of Computer Sciences
Department of Accreditation
Supervision and Scientific Apparatus, Ministry of Higher Education and Scientific Research
Akasser Alabaed str., 608, Akarkh, Baghdad, Iraq, 10011
E-mail: ahmed.qacc@gmail.com

Noor Hasan Hassoon
Lucturer, Master of Computer Sciences
Department of Computer
College of Education for Pure Science*

Layla AL.hak
Lecturer, Master of Computer Sciences
Department of Computer
College of Science*

Mahdi Edan
Doctor of Applied Physics
Department of Computer Techniques Engineering
AL-Rasheed University College
Al- qadesiya str., 602, Baghdad, Iraq, 32001

Hazim Noman Abed
Assistant Professor, Master of Computer Sciences
Department of Computer
College of Science*

Sura Khalil Abd
Doctor of Network and Communication Systems Engineering
Department of Computer Science and Information Technology
Institute of Informatics and Computing in Energy
Universiti Tenaga Nasional
Jalan Ikram-Uniten, Kajang, Selangor, Malaysia, 43000
*University of Diyala
Ba'aqubah str., 25, Diyala, Iraq, 32001

Most security system's essential errand is to check that the people are in fact who they claim to be. In Contrast to traditional techniques such as passwords and smart cards that are used in some organizations, fingerprint identification may be preferred as it makes the information virtually impossible to steal. The most extensive used biometric features are Fingerprints, in order to identify a person because of their uniqueness and invariance. The fingerprint consists of valleys and ridges on the surface of a fingertip. In this paper, a new hybrid strategy Particle Swarm Optimization (PSO) with Bat Algorithm (BA) is proposed to extract features from fingerprint images. Both PSO and BA algorithms are swarm-based algorithms that mimics the swarm behaviour of particles and bats in nature. In the field of image processing, features are extremely significant. Before obtaining features, the noisy area should be removed from the foreground first, and then several important techniques are applied on each sample image in the database such as Fingerprint Enhancement by using Fast Fourier Transform (FFT), Binarization, and Thinning. The hybrid (PSO-BA) algorithm is proposed as a pre-enhancing step to select the clear minutiae (or feature) structures across several iterations, which will be more suited for the matching phase. By comparing the proposed method with several methods in calculating FAR and FRR, the results showed that the FAR (0.001) and FRR (0.01) were less than the other proposed methods. That means the hybrid (PSO-BA) algorithm has the better results, which means it can be used as one of the best search approaches to extract features from fingerprints

Keyword: image processing, biometrics, fingerprint, features extraction, minutiae, binarization, thinning, swarm intelligence, particle swarm optimization, bat algorithm

Received date 08.08.2022
Accepted date 08.10.2022
Published date 30.10.2022

How to Cite*: Ahmed L., A., Hassoon, N., H., AL.hak, L., Edan, M., Abed, H., Abd, S., K. (2022). Features extraction of fingerprints based on hybrid particle swarm optimization and bat algorithms. Eastern-European Journal of Enterprise Technologies, 5 (2 (119)), 55–61. doi: https://doi.org/10.15587/1729-4061.2022.266259*

1. Introduction

Humans can be identified consistent with their diverse characteristics, which sometimes include variation in general appearance or some indication of age. Where it is possible to guess or determine the identity of a person based on the shape of his/her face or when hearing his/her voice. In computer systems, the process of authentication or Identity ver-

Copyright © 2022, Authors. This is an open access article under the Creative Commons CC BY license

ification basically depends on traditional approaches which are password or PIN sometimes refers to the chip card, magnetic card and keys [1]. However, cards or keys oftentimes lost or be stolen as well as passwords oftentimes forgotten or revealed. For more reliable identification or verification, it is necessary to use something that truly determines the person [2].

Biometric systems work to determine a person's identity according to physiological and behavioural biometric data obtained. Signature, speech, keystroke and gait are parameters for behavioral biometric which change with age and environment. In the other side, the physiological characteristic remains without change throughout a person's lifespan such as the face, iris, palm print and fingerprint [3]. Most of the biometrics system operates in single mode, either identification or verification. The choice of mode depends mainly on the requirements of the application. In verification mode, the person ID validation is achieved by comparing captured data of biometric with the off-the-shelf form. Identification mode identifies a user by implementing matches between user fingerprints with several fingerprint biometric templates. In general, fingerprints have been used in everyday life for over 100 years because of their usefulness, uniqueness, durability, reliability, accuracy and acceptability. Each fingerprint consists of furrows, ridges and minutiae that are extracted either by using an impression of ink on a sheet of paper or sensors. A high-quality fingerprint consists of minutes from 25 to 80 based on the accuracy of the sensor and the position of the finger on the sensor. False minutiae caused by the usage of irregular quantities of ink, where the false ridge breaks appear in a state of inadequacy of the ink or cross-connections in a state of excess ink. Fingerprint with poor quality such as fingers disfigured with scars and scratches, injuries or very dry fingers, make It difficult to reliably extract minutia. Usually, fingerprint recognition based on minutia includes some steps like Thinning, extraction, matching and computing score of minutiae matching [4]. An important part of artificial intelligence (AI) is the metaheuristics algorithm, especially Swarm intelligence (SI) algorithms. The main idea of SI derived from the life system of creatures in nature such as bird flocking, ant colonies and animal herding. Most SI algorithm proves their powerful functionality in many applications and computationally intelligent systems [5–7]. In this paper, a hybrid algorithm used for feature extraction, which is Particle Swarm Optimization (PSO) with Bat Algorithm (BA). PSO-BA is one of the recent meta-heuristic optimization algorithms that usually applied in solving optimization problems. In PSO-BA, after running a few fixed iterations, each algorithm replaces its best solution fitness with the worst fitness with the other one. Therefore, a new hybrid strategy Particle Swarm Optimization (PSO) with Bat Algorithm (BA) is used to extract features from fingerprint images. Both the PSO and BA algorithms are swarm-based and imitate the swarm behavior of natural phenomena like particles and bats.

Image processing is an important field and has multiple uses, especially fingerprints, and due to its importance, it attracts researchers to race in order to obtain more accurate results. The PSO algorithm is an algorithm inspired by nature and it has become notable recently due to its strong performance in various fields. Because it makes the data virtually impossible to steal, fingerprint identification may be preferred over more traditional techniques like passwords and smart cards used in some organizations. Due to their consistency and uniqueness, fingerprints are the most commonly used biometric feature for identifying individuals. So, for feature extraction, let's suggest hybrid (PSO-BA) algorithms.

2. Literature review and problem statement

In work [8], a genetic algorithm is proposed in order to develop the image descriptor to extract features from texture images by employing the LBP technique. In addition, they use GP as a way to reducing the max set of feature instances from selected datasets and then comparing them to 7 other datasets. The drawback of this proposed system that the windows size and code length parameters must now be determined empirically.

Paper [2] proposed the Firefly algorithm (FA) as a method to extract features from the image. This algorithm mimics flashing behavior of fireflies in nature. The results show that the proposed algorithm can be utilized as the best search methods. Time execution and not obtaining an optimal solution are a base limitation for this research.

Two-Tier GP and Genetic Programming (GP)-based image classification system that acts on raw pixels only instead of features was introduced by [9]. The first classifier tier is responsible for identifying features automatically depending on raw picture input, while the second classifier tier takes decisions. Two-Tier GP performed better on a variety of tasks when compared to traditional features-based image classification algorithms. Moreover, conventional classification methods outperformed classifying on manually produced features when employing the features defined by the first tier of these Two-Tier GP classifiers. The disadvantage of this research paper is the additional stage for image filtering that makes the Three-Tier is not effective.

The authors of [10] examined the distribution of GP program observations to generate invariant minutiae for the detection of edge. When a set of fundamental invariant features is defined, GP constructs the composite features by employing a piecewise linear and a non-linear relationship connection for CDFs and PDFs to evaluate the evolving program observations. For this investigation, the BSD image dataset benchmark was used. The disadvantage of this paper is summed up time consuming and number of iterations where the algorithm needs more iterations to get better results and that leads to time consuming.

In work [11], the Pareto optimality technique is employed to improve the functional utilized in the Trace transform for obtaining image minutiae which are solid to distortions of RST in the existence of noise. Two slightly different techniques were used to explore the efficiency of producing features that are resistant to the transformations of RST and noise. The results of experiments of both ETT and ETTN on two image databases can extract minutiae that are not affected by RST distortion. The disadvantage of this work that the robustness to noise only be obtained if the Trace transformations are improved while the image samples that utilized in the evolutionary optimization are likewise noisy.

The author of [12] suggested an edge identification approach based on the Green function related to the segmentation model Mumford-Shah. The core of this Green function is a singularity. Therefore, the regularization method is suggested here, in order to achieve the Bessel filter also known as the edge detection filter. This filter is resilient in the presence of noise, and it is easy to install. This filter's scale invariance is proven here. The Bessel filter introduced by the authors can be expanded to extract features from 3D volumetric images. This approach has only been examined on Bessel filter this can be considered as disadvantage for this work.

The paper [13] proposed particle swarm optimization (PSO) as a method to classify and extract features of the image. The efficient performance of the algorithm in a state of sorting or detection tasks by training basically based on extracted features that utilized in the training step. The goal of designing feature is to identify specific key points and key features that are required to identify or classify the desired images. The drawback of this work is that the expert in the area is doing either detection or extraction features since now, which in most state is expensive and hard to use and discover. Therefore, the hybrid algorithm will be proposed to overcome the problems mentioned in previous studies.

3. The aim and objectives of the study

The aim of this study is to extract fingerprint images by propose a Hybrid algorithm and to obtain the best features vector.

To achieve this aim, the following objectives are accomplished:

– to reduce noise and obtain better fingerprint reading, several stages are applied to the fingerprint before using the hybrid algorithm;

– applying hybrid algorithms to minutiae extraction process is to get a core point of the fingerprint;

– to get better results in proper time, using the hybrid (PSO-BA) algorithm as a result of their efficiency, flexibility and good performance in several areas.

4. Materials and methods

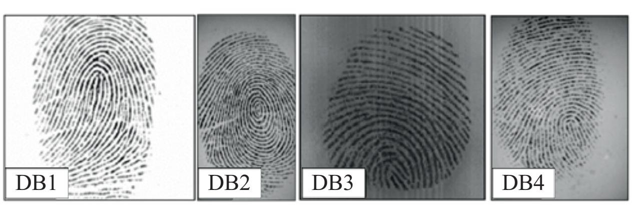
4. 1. Hardware

For implementing work, a Lenovo computer was used. The computer came with core i7 processor and 8GB RAM (China). These specifications utilize in the performance test are considered medium, not high. When a computer with higher capabilities is used, the results will be better.

4. 2. Software

4. 2. 1. The database

The database (Fingerprint Verification Competition) FVC2002 is used through the experiments as shown in Fig. 1.



a *b* *c* *d*

Fig. 1. Images Sample with Different Image Sizes: *a* – TouchView II; *b* – FX2000; *c* – 100 SC; *d* – fingerprint Synthetic [14]

The database (FVC) consists of various databases such as (DB1, DB2, DB3 and DB4) which utilize the following technologies or sensors to collect [15] Table 1:

– DB1: "TouchView II" Optical Sensor by Identix;

– DB2: "FX2000" Optical Sensor by Biometrika;

– DB3: "100 SC" capacitive sensor by Precise Biometrics;

– DB4: fingerprint Synthetic Generator.

Table 1

Database Specifications

DB No.	Image size	Set A(w*d)	Set B(w*d)	Resolution
DB1	388×374(142 Kpixels)	100*8	10*8	500 dpi
DB2	296×560 (162 Kpixels)	100*8	10*8	569 dpi
DB3	300×300 (88 Kpixels)	100*8	10*8	500 dpi
DB4	288×384 (108 Kpixels)	100*8	10*8	About 500 dpi

The wide (w) of the databases are 110 fingers with 8 printers for each finger deep (d) which mean the size of the whole dataset 880 fingerprints as shown in Table 1. Group (B) begin from 101 to 110 fingers which intended for the participants to allow setting parameters before sending algorithms. The dataset is then formed with fingers numbered from 1 to 100 (Group A) [15].

4. 2. 2. Hybrid Particle Swarm Optimization with Bat Algorithm

The structure of the hybrid optimization algorithm is organized by connecting both the strategies of the two algorithms. The main idea of hybrid algorithm depends on replacing individuals between both algorithms according to individual's fitness where the stronger individuals replaced with the weaker individuals of another algorithm in parallel manner processing of intelligent swarm algorithm. The population of the hybrid algorithm is divided into several subpopulations in a parallel structure where each one updated independently in uniform iterations. When the communication strategy is activated then the exchange of information begins between populations. As a result, this process leads to the benefit of taking the individual strengths of both types of the algorithm. However, implementing the process of replacing weaker individuals while running algorithms etc. to benefit from cooperation.

The design of hybrid PSO-BA mainly depends on the original Particle Swarm Optimization with Bat algorithm as shown in Fig. 2 [16].

Both algorithms evolve independently by optimization, for example, BA has its own individuals with better fitness values to replace with the worst individuals of PSO. On another side, the better individuals based on fitness values of the PSO algorithm are replaced with the worst individuals of BA after running some fixed iterations. The max iteration contains R times of communication, where $R=\{R_1, 2R_1, 3R_1,...\}$. Let N be the number of populations of hybrid PSO-BA, and N_1, N_2 are the population's number of PSO and BA respectively, where N_1 and N_2 are set to be $N/2$. If t R , k agents with the top k fitness in N_1 *will* be copied to N_2 *to* replace the same number of individuals with the poorer fitness value, where t denotes the current iteration count, R_1 and k are the predefined constants.

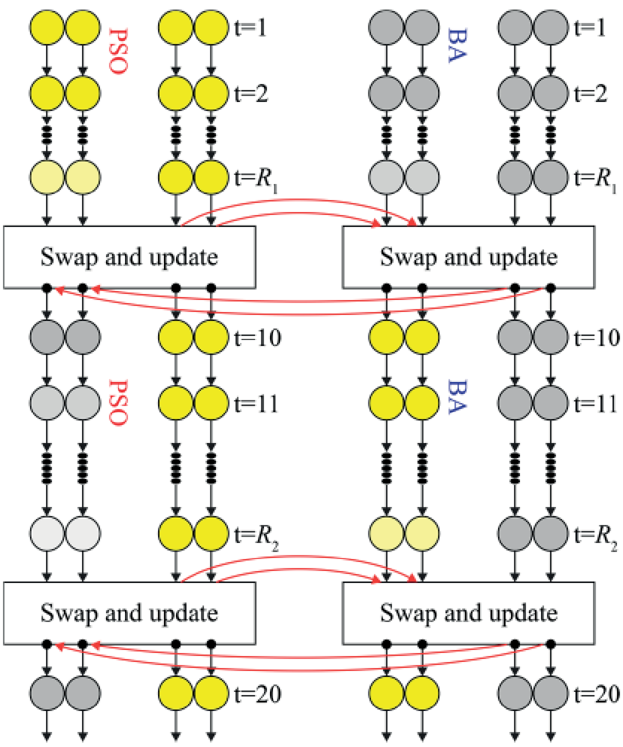


Fig. 2. The communication strategy of the hybrid PSO-BA [16]

5. Results of the study on feature extraction using a hybrid algorithm

5. 1. The basic stage of enhancing image fingerprint

Each input image of a fingerprint must be in a grayscale state whose values of intensity range from 0 to 255. The image of fingerprint consists of the ridges and the valleys. Usually, ridges arise as lines with dark colour whereas the light areas between the ridges know as valleys. The points of minutiae located whenever the ridge becomes intermittent. The situation of ridge either a termination when the ridge comes to an end or a bifurcation when the ridge divides into two ridges. The minutiae have two types of bifurcations and terminations which are more important than other features for further processes of a fingerprint image. Fig. 3 shows the input image of a fingerprint in a grayscale state.

Fig. 3. Fingerprint image

In Fig. 3 the image of the fingerprint consists of the ridges and the valleys. Usually, ridges arise as lines with dark colour whereas the light areas between the ridges are known as valleys. The points of minutiae located whenever the ridge becomes intermittent.

After converting to the grayscale fingerprint image, the Fast Fourier Transform (FFT) analysis is used to enhance the fingerprint image. The performance of features extraction function and matching algorithm of a fingerprint based mainly on the input images quality of fingerprint. While the finger print quality cannot be measured objectively, it is consistent with the structure clarity of the ridge in the fingerprint image, and thus it is needed to improve the fingerprint image. Whereas a fingerprint of 'good' quality has high contrast with well-defined valleys and ridges, a fingerprint of poor quality is characterized by a low contrast and an uncertain boundary between the ridges. The quality of a fingerprint image can be degraded because of several reasons:

1. Ridge discontinuities can be caused by the presence of creases, wounds or bruises.
2. Excessively dry fingers result in ridges that are fragmented and lack contrast.
3. Fingerprint sweat leads to markings that are smudged and parallel ridges are connected. FFT analysis is applied to enhance the fingerprint image as shown in Fig. 4.

Fig. 4. Enhanced fingerprint image

This stage performs the contextual filtering. For each overlapping block in the image, the next step is applied. The converting process of image from the grayscale to the black and white image is known as image binarization [17, 18]. In a Gray-scale image, the pixel values can extend within the range [0, 255], which are 256 different intensity values. While in binary images (Black/White) each pixel is assigned to be either black or white. The conversion from Gray-scale to black and white usually performed by adding threshold to the gray image. When adding a threshold to an image, then all pixels' values are compared to a predefined threshold value. Each pixel value below the first threshold is set to zero otherwise it set to one. At the end of this process, all pixels' value of the image become either zero or one, and consequently a binary is produced. Fig. 5 shows the grayscale fingerprint image that converted to black and white image.

Binarization result of enhanced fingerprint image. By the end of this process, all pixels' values within the image become either zero or one, and consequently a binary is produced. Following the binarization step, another key pre-processing technique used on the image is called thinning as shown in Fig. 6. Ridge thinning is the process of removing unnecessary pixels from ridges until the ridges are only one pixel wide. The thinning algorithm is iterative and parallel. It represents an A 3×3 window moved down the image, then calculations are performed on each pixel to determine whether it is necessary to remain in the image or not. The pixels surrounding the middle pixel are described and classified in the window. The algorithm continuously runs two sub-iterations till the image reaches a stable state. Other Morphological operations are used to remove some isolated points, H breaks, and spikes from the thinned ridge map. In this step, noise processing means that eliminate any single points whether they are single-point breaks in a ridge or single-point ridges.

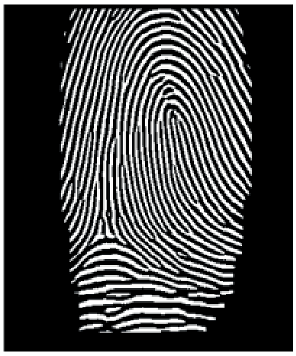


Fig. 5. Binarization

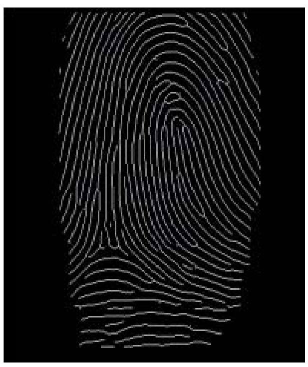


Fig. 6. Result of Thinning Process

As shown in Fig. 6, the thinning process removes unnecessary pixels from ridges until the ridges are only one pixel wide. Also remove some H breaks, isolated points and spikes.

5. 2. Feature extraction for fingerprint image

The first step in the actually minutiae extraction process is to get a core point of the fingerprint as shown in Fig. 7.

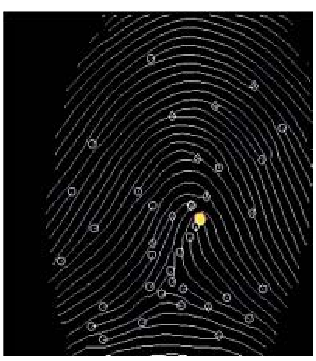


Fig. 7. Representation of Core Point, Bifurcations and Terminations

Main idea of the core point determination is taken from what is illustrated as follow: The reference point can be defining as "the point of the maximum curvature on the convex ridge" that usually exists in the middle area of the fingerprint. Detecting the maximum curvature using complex filtering methods can be used to reliably detect the reference point position. Several complicated filters are applied on orientation field of the ridge produced from the original image of a fingerprint. The filtered image that responds to the maximum complex filter can be characterized as a reference point. Due to there is a uniquely output, then this output point is used as a reference point (core point).

Once the binary image has been gained, a simple image checking in order to detect the corresponding pixels to minutiae. The ridge endings and bifurcations of minutiae are extracted by the hybrid algorithm that searches among local neighborhoods of each ridge pixel in the image, in order to get the best features. As a result, for each minutia three pieces of information which are x and y coordinates of minutiae location are sorted for both minutia type such as a termination represented as type 1 while a bifurcation represented as type 2. All minutia information is used to evaluate performance rate.

5. 3. Performance evaluation for the hybrid algorithm

This section presents the performance of the proposed the hybrid (PSO-BA) algorithm based on biometric authentication techniques. To verify the strength of that, there are two most important metrics used to evaluate the performance of the biometric authentication. The first one is False Rejection Rate (FRR) and the second one is False Acceptance Rate (FAR). FRR means not to authorize an authorized person. The FAR means giving authorization to an unauthorized person [19]. Both FAR and FRR must be as low as possible, but both are antagonists and part of an intricate balancing act as shown in Table 2.

Table 2

FAR, FRR results with their corresponding thresholds

Cases	FAR	FRR	TH1	TH2
Case1	0.004	0.06	18	11
Case2	0.005	0.02	20	11
Case3	0.007	0.04	19	12
Case4	0.001	0.01	15	13
Case5	0.005	0.007	17	14

The matching results are obtained between images from different classes. The matching period took about 1 second per user. The FAR result is 0.004 and the FRR result is 0.06 for the threshold1 (TH1)=18 and threshold2 (TH2)=11 when increased TH1 to 20 with the same value to TH2, the FAR became 0.005 and FRR=0.02 and so on. The best result obtained in FAR when the threshold value 15 and 13 for TH1 and TH2 respectively. While the best results obtained in FRR when the threshold value 17 and 14 for TH1 and TH2 respectively. We got good results due to the quality of the features chosen by the hybrid algorithm. Our method is better when comparing results with [20] based on FAR and FRR values, especially in the four and the five cases. While the FAR and FRR of [20] equal to 0.0154 and 0.0137 respectively less than our results. The rest of the results are very close.

Table 3

FAR, FRR results with their corresponding approaches

Approaches	FAR	FRR
(Liu & Cao 2012) [21]	0.085	1.4
(Ishpreet et al.2012) [22]	0.06	6.9
(Atul S. Chaudhari2014) [23]	0.23	0
(Ali, Mouad MH, et al.2016) [18]	0.20	0.19
Our Approach	0.001	0.01

Table 3 shows the comparison between the proposed method with several methods in calculating FAR and FRR, where [21] used the ant colony algorithm and obtained 0.085 and 1.4 for FAR and FRR respectively. In [18, 22, 23], the authors used typically feature extraction with some different additions in order to get better results. However, [22] obtained FAR 0.06 and FRR 6.9. In [23], the authors got FAR 0.23 and FRR 0. The FAR and FRR for [18] are 0.20 and 0.19 respectively while our proposed method FAR 0.001 and FRR 0.01. Almost we got better results where the ratios of FRR and FRR ratio were balanced and minimal. The accuracy and elapsed time are exceptional with the proposed method. Approximately the time used for implementation ranges from 2 to 3 minutes, and this often depends on the quality of the device used in the work. The FAR and FRR, the more convenient a security system is for a user.

6. Discussion of the results of the studying fingerprint feature extraction by using a hybrid algorithm

In this section the results obtained after testing the proposed hybrid (PSO-BA) algorithm will be discussed further.

The Fig. 3–6 represent the enhancement process of fingerprint image in order to remove (isolated points, spikes, and some H breaks) and get better results.

Fig. 7 represents core point, bifurcations and terminations, where the ridge endings and bifurcations of minutiae are extracted by the hybrid algorithm that searches among local neighborhoods of each ridge pixel in the image, in order to get the best features.

In Table 2 the False Acceptance Rate (FAR) and False Rejection Rate (FRR) results with their corresponding thresholds are computed. Which means giving authorization to an unauthorized person while the other means not authorizing an authorized person respectively. Both of must be as low as possible, but both are antagonists and part of an intricate balancing. The results of FFR and FAR were affected by the randomness of both PSO and BAT algorithms.

In Table 3 the results showed that the proposed method had lower FAR (0.001) and FRR (0.01) values than the other proposed methods when compared with several other methods for calculating FAR and FRR. As a result, the hybrid (PSO-BA) algorithm provides better results, making it one of the best search strategies for identifying fingerprint features.

As limitations, the time taken by the proposed the hybrid (PSO-BA) algorithm to show results is equal to one second per user. The time can be less if the specifications of the device are higher than the specifications of the device used in this research. Also, the increase in the number of iterations in the proposed hybrid (PSO-Bat) algorithm was the reason for the satisfactory results, as well as it causes a delay in time, in addition the hybrid algorithm is mathematically complex because it requires taking the derivative of the ratio for some parameters.

7. Conclusions

1. Several steps have been implemented to enhance the image to obtain a better fingerprint reading.

2. The features extraction has been suggested and illustrated for fingerprint images by utilizing Hybrid (PSO-BA) algorithm. The hybrid algorithm applied to the search feature space of the image in order to get the best features vector. The results obtained showed the quality of the features extracted using the PSO-BA algorithm, as well as the superiority of this optimization technique in terms of speed of performance.

3. The matching results are obtained between images from DB1 to DB4, taking about 1 second per user. According to FAR and FRR, good results obtained, due to the quality of the features chosen by the hybrid algorithm.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

References

1. Tarjoman, M., Zarei, S. (2008). Automatic fingerprint classification using graph theory. In Proceedings of world academy of science, engineering and technology.
2. Al-Ta'l, Z. T. M., Abdulhameed, O. Y. (2013). Features extraction of fingerprints using firefly algorithm. Proceedings of the 6th International Conference on Security of Information and Networks - SIN '13. doi: https://doi.org/10.1145/2523514.2527014
3. Zhang, D. D. (2000). Automated biometrics: Technologies and systems. Springer, 332. doi: https://doi.org/10.1007/978-1-4615-4519-4
4. Ravi, J., Raja, K. B., Venugopal, K. R. (2009). Fingerprint recognition using minutia score matching. International Journal of Engineering Science and Technology, 1 (2), 35–42. doi: https://doi.org/10.48550/arXiv.1001.4186
5. Abed, H. N., Ahmed, A. L., Hassoon, N. H., Albayaty, I. S. (2018). Hiding Information In An Image Based On Bats Algorithm. Iraqi Journal of Information Technology, 8 (2). doi: https://doi.org/10.34279/0923-008-002-011
6. Bonabeau, E., Dorigo, M., Theraulaz, G. (1999). Swarm intelligence: from natural to artificial systems. Oxford Academic. doi: https://doi.org/10.1093/oso/9780195131581.001.0001
7. Teodorovic´, D. (2003). Transport modeling by multi-agent systems: a swarm intelligence approach. Transportation Planning and Technology, 26 (4), 289–312. doi: https://doi.org/10.1080/0308106032000154593

8. Al-Sahaf, H., Al-Sahaf, A., Xue, B., Johnston, M., Zhang, M. (2016). Automatically Evolving Rotation-invariant Texture Image Descriptors by Genetic Programming. IEEE Transactions on Evolutionary Computation. doi: https://doi.org/10.1109/tevc.2016.2577548
9. Al-Sahaf, H., Song, A., Neshatian, K., Zhang, M. (2012). Two-Tier genetic programming: towards raw pixel-based image classification. Expert Systems with Applications, 39 (16), 12291–12301. doi: https://doi.org/10.1016/j.eswa.2012.02.123
10. Albukhanajer, W. A., Briffa, J. A., Yaochu Jin. (2015). Evolutionary Multiobjective Image Feature Extraction in the Presence of Noise. IEEE Transactions on Cybernetics, 45 (9), 1757–1768. doi: https://doi.org/10.1109/tcyb.2014.2360074
11. Mahmoodi, S. (2012). Edge Detection Filter based on Mumford–Shah Green Function. SIAM Journal on Imaging Sciences, 5 (1), 343–365. doi: https://doi.org/10.1137/100811349
12. Athira Lekshmi, B. A., Linsely, J. A., Queen, M. P. F., Babu Aurtherson, P. (2018). Feature Extraction and Image Classification Using Particle Swarm Optimization by Evolving Rotation-Invariant Image Descriptors. 2018 International Conference on Emerging Trends and Innovations In Engineering And Technological Research (ICETIETR). doi: https://doi.org/10.1109/icetietr.2018.8529083
13. Kareem Rasheed, M., Dawood, A. J. (2019). A new card authentication schema based on embed fingerprint in image watermarking and encryption. Journal of Theoretical and Applied Information Technology, 97 (3), 1018–1029. Available at: http://www.jatit.org/volumes/Vol97No3/26Vol97No3.pdf
14. Maio, D., Maltoni, D., Cappelli, R., Wayman, J. L., Jain, A. K. (2004). FVC2004: Third Fingerprint Verification Competition. Lecture Notes in Computer Science, 1–7. doi: https://doi.org/10.1007/978-3-540-25948-0_1
15. Pan, T.-S., Dao, T.-K., Nguyen, T.-T., Chu, S.-C. (2015). Hybrid Particle Swarm Optimization with Bat Algorithm. Genetic and Evolutionary Computing, 37–47. doi: https://doi.org/10.1007/978-3-319-12286-1_5
16. Liao, M., Wan, Z., Yao, C., Chen, K., Bai, X. (2020). Real-Time Scene Text Detection with Differentiable Binarization. Proceedings of the AAAI Conference on Artificial Intelligence, 34 (07), 11474–11481. doi: https://doi.org/10.1609/aaai.v34i07.6812
17. Mingote, V., Miguel, A., Ribas, D., Ortega, A., Lleida, E. (2019). Optimization of False Acceptance/Rejection Rates and Decision Threshold for End-to-End Text-Dependent Speaker Verification Systems. Interspeech 2019. doi: https://doi.org/10.21437/interspeech.2019-2550
18. Ali, Mouad. M. H., Mahale, V. H., Yannawar, P., Gaikwad, A. T. (2016). Fingerprint Recognition for Person Identification and Verification Based on Minutiae Matching. 2016 IEEE 6th International Conference on Advanced Computing (IACC). doi: https://doi.org/10.1109/iacc.2016.69
19. Rao, G. S., NagaRaju, C., Reddy, L. S. S., Prasad, E. V. (2008). A novel fingerprints identification system based on the edge detection. International Journal of Computer Science and Network Security, 8 (12), 394–397. Available at: http://paper.ijcsns.org/07_book/200812/20081256.pdf
20. Kukula, E. P., Blomeke, C. R., Modi, S. K., Elliott, S. J. (2009). Effect of human-biometric sensor interaction on fingerprint matching performance, image quality and minutiae count. International Journal of Computer Applications in Technology, 34 (4), 270. doi: https://doi.org/10.1504/ijcat.2009.024079
21. Cao, K., Yang, X., Chen, X., Zang, Y., Liang, J., Tian, J. (2012). A novel ant colony optimization algorithm for large-distorted fingerprint matching. Pattern Recognition, 45 (1), 151–161. doi: https://doi.org/10.1016/j.patcog.2011.04.016
22. He, Y., Tian, J., Luo, X., Zhang, T. (2003). Image enhancement and minutiae matching in fingerprint verification. Pattern Recognition Letters, 24 (9-10), 1349–1360. doi: https://doi.org/10.1016/s0167-8655(02)00376-8
23. Chaudhari, A. S., Patnaik, G. K., Patil, S. S. (2014). Implementation of Minutiae Based Fingerprint Identification System Using Crossing Number Concept. Informatica Economica, 18 (1), 17–26. doi: https://doi.org/10.12948/issn14531305/18.1.2014.02