A Cuckoo Search Algorithm for Fingerprint Image Contrast Enhancement

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Abstract—**The quality of fingerprint images strongly affects any fingerprint biometric system. In order to deal with low quality fingerprint images and overcome the limits of traditional enhancement techniques, a cuckoo-search based algorithm for fingerprint image contrast enhancement is proposed in this paper. The algorithm combines the use of cuckoo search for both the gray level mapping technique for contrast enhancement, and a new objective function as a quality metric for global fingerprint image enhancement. The enhancement scheme is assessed on low quality images from a reference database, the FVC 2000. The obtained results show that the proposed cuckoo algorithm can qualitatively and quantitatively enhance fingerprint images, on the general level of both noise eradication and quality metrics. In addition, the proposed algorithm can visually and numerically clarify the fingerprints ridge structure, thus, the minutiae detection process in comparison with the use of a traditional enhancer. Hence, the proposed algorithm has proven to be very efficient for fingerprint image quality enhancement for easy further processing.**

Keywords-component; fingerprint recognition; fingerprint image contrast enhancement; cuckoo search; gray level mapping.

I. INTRODUCTION

Biometric based systems provide more security advantages over traditional based systems such as negative recognition and nonrepudiation possibilities. Due to its uniqueness, stability and permanence, automatic fingerprint systems (AFS) have been the most popular and one of the most reliable biometric systems [1]. Like any other biometric technology, feature extraction is a crucial phase in any AFS. These features mainly represent ridge patterns and the minutiae laying within fingerprints impressions. The process of fingerprint image acquisition, by pressing or rolling a finger against a hard surface, is generally affected by some distortions and degradations caused by several subject or sensor-based parameters.

These distortions may heavily affect the extraction phase since they are function of the impact on the spatial representatives of the fingerprint template. To this end, an enhancement procedure is necessary before tackling the automatization process. Many methods have been applied over the literature to enhance such images. Each approach is consistent to a given extractor and a nature of the patterns to be extracted within a determined domain. Enhancement methods mostly function as noise reducers and contrast increasers, between ridges and valleys of the fingerprint images. The existing enhancement methods differ from binarisation and filtering to the manipulation of gray levels, which are mostly exhaustive pixel-manipulating techniques.

In this context, the proposed approach consists of using the recently proposed Cuckoo Search (CS) metaheuristic [2] for gray level fingerprint contrast enhancement. The new gray level distribution is optimally obtained through the process of CS and used to replace the original gray levels of the fingerprint input image. A new objective function is used which makes use of the entropy of the whole image for better qualitative and statistical results. The proposed approach is validated on some benchmark fingerprint images obtained from the database FVC2000. Our approach statistically and qualitatively outperforms other state-of-the-art enhancers on the level of general image quality improvement. The approach is also validated through numerical comparisons against one [3] of the fingerprint enhancement techniques and promising results are obtained.

The remainder of this paper is organised as follows. Section 2 provides a general introduction to fingerprint recognition and the Cuckoo Search metaheuristic, it also reviews the main spatial-domain image enhancement techniques. Section 3 describes our proposed approach. Section 4 summarizes the obtained experimental results and details our comparisons. Finally, a conclusion and research perspectives are drawn up in Section 5.

II. BASIC CONCEPTS

A. Fingerprint Recognition

Fingerprints have been widely and successfully used for personal identification both before and after the automatisation of finger-based systems, thanks to their individuality, stability through life, uniqueness among people, public acceptance and their minimum risk of intrusion [4]. Fingerprint technology is a biometric technique which is utilized to identify persons based on their physical traits. These physical patterns consist of ridges and valleys existing on the surface of fingertips. Fingerprints' features are divided into two types: the ridge patterns' orientation and frequency being global features on the one hand, and the minutiae, mostly system-based used, being the local features laying with regular flow for personal distinctive representation on the other hand [5].

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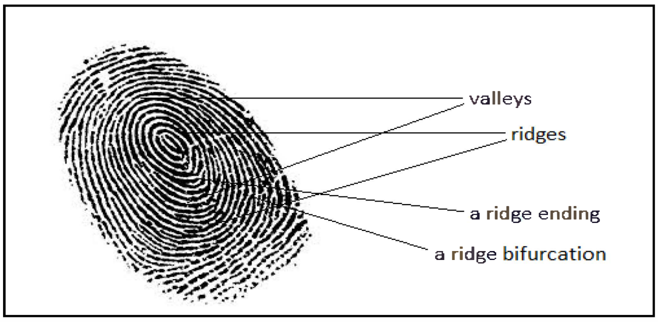

Figure 1. Representation of ridges (endings/bifurcations) and valleys within a fingerprint impression

Like any other biometric system, fingerprint systems comprise four modules. The sensor module is for acquiring raw fingerprint impressions. The quality assessment and feature extraction module is dedicated to the pre-processing and extraction of salient characteristics. The matching and decision-making module is used to authenticate or reject a person on the basis of the comparison of the matching score between his query features and those stored in the system database module, which stores all the extracted biometric samples during the enrolment process [6]. Many biometric fingerprint systems have been proposed in literature. They have relatively given good rates in terms of both verification and identification [7].

B. *Fingerprint Enhancement Techniques*

Many representations of fingerprint biometrics have been used in literature. A common part between all these systems is that the efficiency of any of them strongly depends on the quality of the input image. Several techniques have been proposed for fingerprint image enhancement, whether being a binary or gray-level image. These methods can be divided into spatial and frequency domain techniques, in addition to fuzzy-based techniques. Enhancement techniques mainly aim at reducing noise and increase contrast between ridges and valleys. Since our approach belongs to the spatial-domain type of techniques, we cite here a brief review of approaches known in literature for domain-based enhancement methods.

In 1989, Jain [8] proposed a band pass filter for ridge extraction to reduce noise and preserve the true ridges and structures. Four years later, Hung proposed the extraction of information about local ridges/valleys structures for improving the basic ridges extraction approach [9]. Hong et al. in [10] proposed a fast finger enhancement based on the estimated local ridge orientation and frequency for adaptive improvement of ridge and valley structure's clarity. For fingerprint ridge extraction, Greenberg et al. in [3] proposed two other methods for ridge enhancement. The first consists of the use of local histogram equalization, Weiner filtering and image binarisation, while the second uses a unique anisotropic filter for direct gray-scale enhancement.

In reference [11], Kim et al. proposed two enhancement algorithms, an adaptive image normalization based on block processing and a Gabor filter devised with a new technique for selection of two important parameters of this one. Zhang et al. [12] proposed a space-frequency federated filtering scheme with an ability to adapt filtering methods to the input images according to a pre-defined calculated factor. Yang et al. [13] proposed a new filter design named the *Modified Gabor filter*, which accurately improves the traditional Gabor filter in terms of both preserving the image structure and enhancement consistency.

In 2004, Wu et al. [14] proposed a composite filter which integrates the advantages of both directional median and anisotropic filters. A year later, Khan et al. [15] proposed a decimation-free directional filter to provide an output in the form of directional images, to be compared against each others in order to pick up the one having the best energy.

Yun and Cho in [16] proposed an adaptive pre-processing method to improve fingerprint image quality. Fronthaler et al. [17] proposed an image-scale pyramid followed by a contextual filtering where the corresponding directions are derived from the frequency-adapted structure tensor. Sepasian et al. in [18] proposed the use of contrast limited adaptive histogram equalisation together with clip limit, standard deviation and sliding neighbourhood as a three-step procedure for fingerprint enhancement. Jun-tao et al. [19] devised an enhancement algorithm based on edge filter for edge enhancement as well as image segmentation and Gabor filter to fulfill the enhancement task.

Yoon et al. in [20] presented a novel orientation field estimation algorithm which fits orientation field model to coarse orientation filed estimated. Choudhary et al. [21] presented a method based on the frequency and spatial domain filtering; local orientation and frequency estimation and morphological operation for low quality fingerprints. Babatunde et al. [22] modified existing mathematical models for fingerprint segmentation, normalisation, ridge orientation estimation, ridge frequency estimation, Gabor filtering, binarisation and thinning all together for fingerprint image enhancement.

C. *Cuckoo Search*

Cuckoo search (CS) is a recent population-based metaheuristic first proposed Yang and Deb in 2009 [2]. This metaheuristic is inspired by the parasitic breeding behaviour of some cuckoo species. In short, the CS algorithm reveals and idealizes the aggressive reproduction strategy of some cuckoo species depending on other species host birds' nests for laying their eggs. The host birds nurture these eggs assuming them as their own, and alien eggs are discarded if being recognized with some probability.

As a result, the host birds either throw away the recognized eggs or dump the old nests, and build new nests in new random positions. Each egg in a nest represents a solution and a cuckoo egg represents a new solution. Hence, this algorithm as an optimization tool has the objective to find the best nest having the best quality eggs considering the basic rules underlined in the original proposed CS [2]. Fig 2 represents the general pseudo-code summarizing the basic cuckoo search steps [23].

```
Begin
  Objective function f(x), x=(x1, …, xd)^T
  Generate initial population of n host nests xi (i=1,2, …, n)
  while (t < MaxGeneration) or (stop criterion)
    Get a cuckoo randomly by Lévy flights
      Evaluate its fitness Fi
    Choose a nest among n (say j) randomly
    if (Fi > Fj)
      Replace j by the new solution;
    end
    A fraction (Pa) of worse nests are abandoned and new ones are built
    Keep the best solutions (nests with quality solutions);
    Rank the solutions and find the current best
  end while
  Post process results and visualization
end
```

Figure 2. The pseudo-code of the Cuckoo Search algorithm

The three rules to be considered are:

- Each cuckoo lays one egg at a time and dumps it in a randomly chosen nest.
- The best nests with high quality of eggs will carry over to the next generation.
- The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability $p_a \in [0, 1]$.

First, the objective function *f(x)* is to be chosen and set as the fitness function of the maximisation or the minimisation treated problem, and the population *Pop(n)* is initialised to suit the problem dimension. Then, new solutions $X_i^{(t+1)}$ are produced by the performance of *Lévy flights* using (1), where α $(\alpha > 1)$ is the step size related to the optimisation problem, the product $\otimes$ is an entry-wise multiplication with the random *Lévy* distribution gotten from (2).

$$X_i^{(t+1)} = x_i^t + \alpha \otimes Lévy(\lambda) \quad (1)$$

$$Lévy \sim u = t^{-\lambda}, \text{ where } 1 < \lambda \leq 3 \quad (2)$$

This process translates both exploitation through the fact that some of the newly produced solutions should be generated near the best solution obtained so far, and exploration thanks to the newly generated solutions generated far enough from the current best solutions.

Since its introduction, the simple CS algorithm was used in many fields and proved its efficiency compared to existing metaheuristics [24], [25]. It has been used into engineering optimization problerm [26], for data fusion in wireless sensor networks [27], for solving NP-hard combinatorial optimization problems [28], for developing new testing approaches [29], for optimising the web service composition process and planning graphs [30], for embedded system design [31], for milling applications [32], and also for manufacturing scheduling [33].

III. The Proposed Cuckoo Search Algorithm for Fingerprint Image Contrast Enhancement

A. Motivation

Like all other automatic systems based on images, image enhancement is crucial in any fingerprint system. In fingerprint systems, acquired images are generally affected by the acquisition process like most other biometric systems. Distortions are induced due to this process because of many parameters. These introduced distortions on the level of ridge structure will affect the spatial locations of minutiae, the representatives of distinctive fingerprints. Hence, the output (decision) of the minutiae-based system is affected.

Within the enhancement process itself, the binary images mostly apply binarisation as a pre-enhancing step, which will cause a generation of more spurious minutiae structures due to the aberrations and irregularities of the binary fingerprint images, a loss of valuable raw fingerprint information, and the difficulty of further enhancement and processing techniques such as *thinning*. Gray-level fingerprint images enhancement, on the other hand, does not alter the original ridge structure, but may be heavily affected by the raw fingerprint image to be processed and the important amount of noise within it.

As already mentioned, many techniques of binary or gray level images enhancement have been proposed for contrast improvement and image quality refinement, from one side. From the other side, optimisation techniques have been also introduced in image enhancement as software algorithms to support the hardware devices for elaborating qualitative images for further processing [34] [35] [36].

In addition, the CS algorithm has proven to be superior than most of the already pointed to algorithms in many optimization contexts. The obtained results reported by the authors in [34, 35, 36] were of a great motivation to use the recently proposed CS algorithm to solve the same problem; our context is the use of such a simple and efficient algorithm in a real-time application, fingerprint image enhancement, where the results in terms of time and efficiency are of a great importance. Traditional pixel oriented image enhancers rely on exhaustive-search which is conceptually very time-consuming. Hence, we propose a CS algorithm for fingerprint image contrast enhancement for searching the best alternative gray level distribution for the input fingerprint.

B. The Proposed Algorithm

The paper in hand presents the use of a CS algorithm as an optimiser for histogram manipulation of fingerprint images to enhancement ends. In other words, contrast enhancement is considered as an optimisation problem, where the output should be a new distribution of gray level of the input fingerprint image. This new set is obtained through the CS metaheuristic to overcome the traditional exhaustive search-based pixel oriented enhancers. In this respect, considered as an optimization problem, the contrast enhancement problem requires the definition of the representation of solutions and the objective function which will be next covered in the present section. The whole process of the CS for optimal gray level mapping will be then detailed.

- **Representation of solutions**

The same vectorial representation of solutions used in [36] is adopted in this work. It defines a solution to the problem as an ordered vector of *D* integers in the interval of [0, 255] for a possible mapping, where *D* is the number gray levels existing in the input image. Fig 4 represents an ascendantly ordered vector of gray levels in an input image and its histogram as well as a solution to the mapping problem on the level of the output image and its histogram.

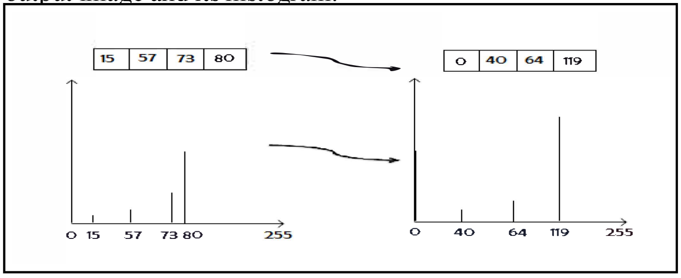

Figure 3. Gray level mappings and solution representation

The mapping operation applies the correspondence of each gray level in the input image to its equivalent in the solution vector. The running of the mapping function within the previous example holds the following description for the output pixels intensities respecting both the order and the correspondence issues where *f(15)=0, f(57)=40, f(73)=64, f(80)=119*.

- **Objective function**

Considering the spatial domain, any transformation function can be represented as *g(x,y)=T[f(x,y)]*, where *f(x,y)* is the input image pixel, *g(x,y)* is the enhanced image pixel, and *T[]* is the transformation operator on *f*.

In this work, we adopted a new formula (3) where both of the number of edge pixels and the intensities of edge pixels are combined with the entropy of the whole image to complete the formula used in [36]. The latter does not include the entropy component. The entropy component has been added to be maximised, to control the unnatural looking effect obtained by traditional enhancers, hence, a better quality images will be produced.

$$F(Z) = log(log(E(I(Z)))).\frac{ne(I(Z))}{PH \times PV}.H(I(Z)) \tag{3}$$

In the formula:

- *F(Z)* represents the quality of the output image obtained from the use of the mapping represented by the solution vector Z on the input image I;
- *E(I(Z))* is the sum of edge intensities of the image resulting from filtering the output image *I(Z)* by the *Sobel filter*;
- *Ne(I(Z))* is the number of the edges in the same resulting image;
- *H(I(Z))* is the entropy of the output image;
- *PH* and *PV* are the numbers of horizontal and vertical pixels of the image respectively.

- **The search process**

In our enhancement approach, a CS algorithm is used as an optimiser to look for the best gray level distribution that maximises the objective function. Fig. 5 outlines the set of steps to be applied on the input fingerprint image once it is introduced to the system.

a. Initialization: An initial population of solutions Pop_0 is generated. It is composed of *N* ascendantly ordered vectors having values in the interval [0,255]. *N* represents the number of solutions; it is the number of both cuckoos and nests, since we adopted the simplest representation where one cuckoo is assumed to be per nest. The number of elements of these vectors is *D*, which represents the number of gray levels of the input image.

After this initialization step, the algorithm cyclically repeats the following steps until a predefined number of iterations, being the current chosen stop condition, is met.

b. Generate new solutions: A random solution is chosen and perturbed. The new generated solution to replace the randomly chosen one is gotten using the Lévy flight principle described in Equation (1).

c. Correction: The generated solution gets a correction operation: The correction operation includes discretising, sorting, and bounding. The need of the correction operation is justified by the requirements of the discrete treated problem (mapping gray levels), since the Lévy flight equation works in the continuous space, discretisation is needed. The bounding operation enables restricting the elements of the newly generated solution between 0 and 255.

d. Evaluation: The newly generated solution is then evaluated. The evaluation of a given solution means the calculation of the objective function described in equation (3) on an output enhanced image where its input image got an enhancement using the solution in question for gray level mapping.

e. Choose a random solution: A solution is then randomly chosen from the population: The choice is performed according to a fraction of probability. The solution is then evaluated.

In this step, a comparison is committed between the newly generated solution and the randomly chosen one: The solution to be kept is the one having the best objective function after have been evaluated on the image to be enhanced.

f. Replacement: In this step, a portion of the worst solutions are discarded and replaced by new randomly generated ones. The new generated solutions are corrected to be part of the search process and further used.

g. Check stop condition: If the stop condition is met, the best so far gotten solution is applied to transform the input fingerprint image into the enhanced one and the result is visualized and used in further processing.

IV. EXPERIMENTAL RESULTS

To evaluate its performances, the proposed algorithm, has been applied on a set of low quality gray scale fingerprint images gotten from the standard database FVC 2000 [37]. The evaluation process consists of two parts to cover the enhancing effect on the level of the general image quality improvement, and on the level of the brought specificities to the fingerprint image. The following sub-sections sum up qualitative and numerical comparisons to a traditional enhancer for the validation process.

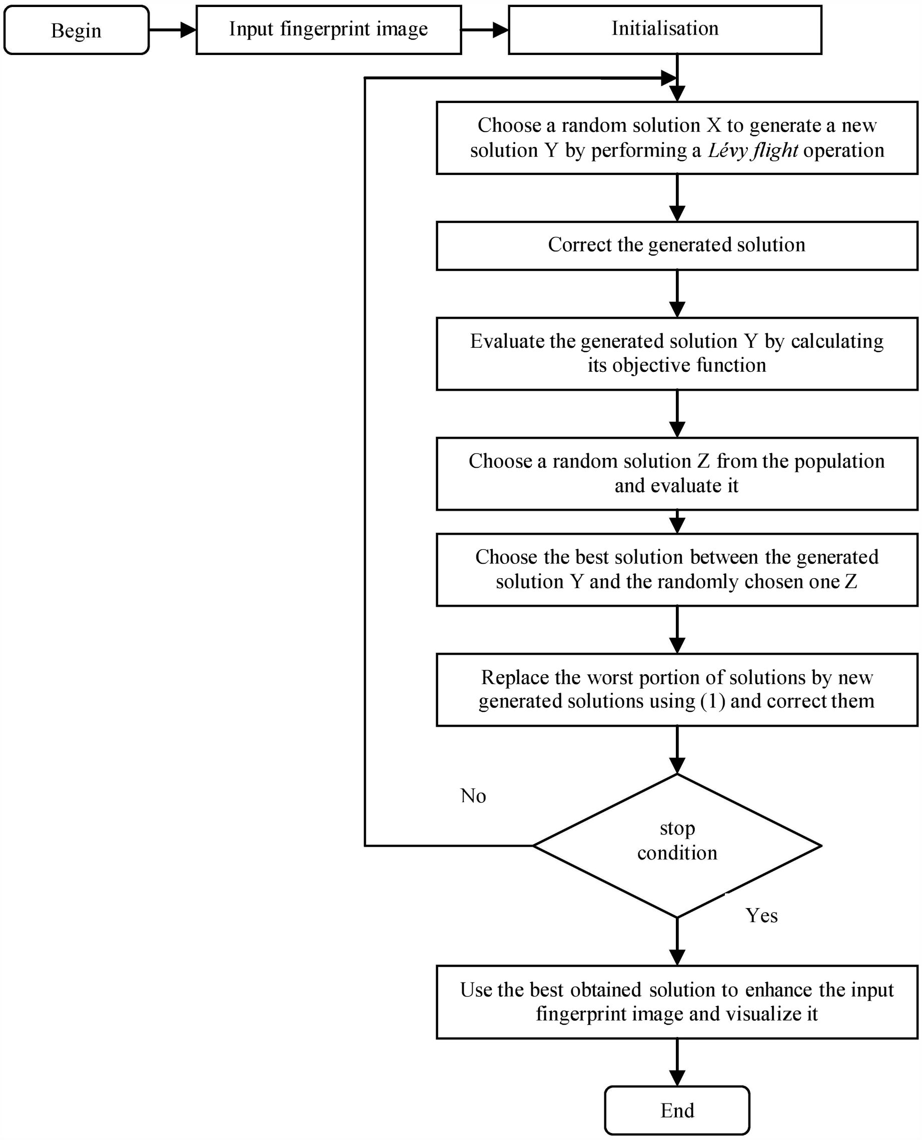

Figure 4. The proposed CS approach for fingerprint contrast enhancement

A. *Validation with regard to Image Quality*

The proposed algorithm is first compared to the most currently used techniques when it comes to contrast enhancement and the manipulation of gray levels, namely histogram equalization (HE), histogram stretching (HS) and adaptive histogram (AH). To assess the appropriateness of the enhanced images using the already mentioned techniques and our proposed one, both the entropy and the PSNR (Peak Signal to Noise Ratio) values are calculated, where each is to be maximised for better image quality.

Qualitatively speaking, Fig. 5 provides the obtained results from the application of the proposed algorithm and the HE technique. Fig 5 shows from left to right, the instances of input fingerprint images, the resulting images from HE application and their equivalent histograms, and the resulting images obtained by our approach and their equivalent histograms.

From these results (Fig. 5), it is well seen that the fingerprint image quality has successfully improved using the proposed CS algorithm. In addition, the histograms of the enhanced output images using the proposed algorithm include more gray levels, stretched over the range [0, 255], which confirms the superiority of the proposed approach.

Statistically speaking, Tables 1 and 2 provide the results of the comparison of our algorithm to the HE, HS and AH techniques, the most used techniques over the literature for contrast enhancement, where the quality of the enhanced images is calculated using the entropy as well as the PSNR metrics on the benchmark fingerprint images.

As seen from Tables 1 and 2, the proposed CS algorithm has given better results than both HE and HS in terms of the entropy. 80% was the success rate of the CS over the AH for the same evaluation. For the PSNR metric, our proposed CS algorithm outperformed the HE enhancer, gave 80% and 70% success rates for both HS and AH respectively.

The obtained results are demonstrative of the improvement of fingerprint images on the level of noise eradication and general quality enhancement.

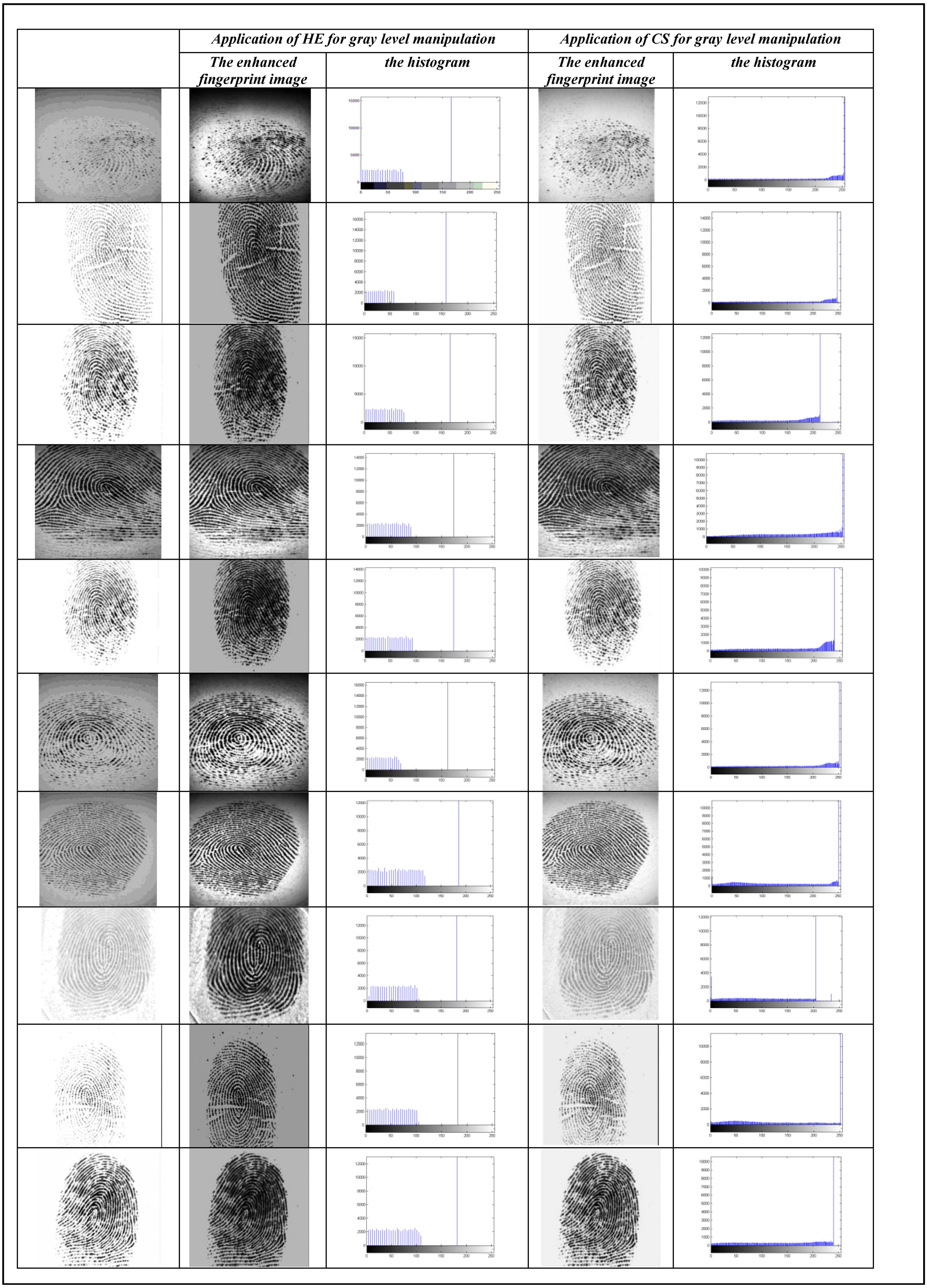

Figure 5. Visual and histogram-based evaluation of the proposed approach

TABLE 1 COMPARING THE ENTROPY VALUE FOR THE HE HS AH AND THE PROPOSED CS METHODS

	HE enhancer	*HS enhancer*	*AH enhancer*	*The proposed CS enhancer*
Fingerprint Image 1	5.6755	6.16	6.88	**6.92**
Fingerprint Image 2	2.83	3.63	4.53	**5.23**
Fingerprint Image 3	2.97	3.86	4.44	**4.86**
Fingerprint Image 4	5.97	7.38	7.86	**7.88**
Fingerprint Image 5	2.74	3.73	**4.87**	**4.62**
Fingerprint Image 6	5.90	6.67	7.50	**7.67**
Fingerprint Image 7	5.85	6.63	7.70	**7.61**
Fingerprint Image 8	5.71	6.04	4.74	**6.80**
Fingerprint Image 9	1.43	1.99	2.45	**3.52**
Fingerprint Image 10	3.05	4.33	**7.47**	**5.15**

TABLE 2 COMPARING THE PSNR VALUES FOR THE HE HS AH AND THE PROPOSED CS METHODS

	HE enhancer	*HS enhancer*	*AH enhancer*	*The proposed CS enhancer*
Fingerprint Image 1	12.09	**15.89**	**22.01**	**15.16**
Fingerprint Image 2	6.70	19.19	17.41	**19.70**
Fingerprint Image 3	7.65	17.91	18.22	**18.38**
Fingerprint Image 4	18.60	16.05	15.33	**19.38**
Fingerprint Image 5	7.40	19.55	19.08	**20.98**
Fingerprint Image 6	13.94	14.81	15.45	**15.75**
Fingerprint Image 7	14.17	14.46	**18.99**	**14.73**
Fingerprint Image 8	7.27	10.74	13.40	**20.95**
Fingerprint Image 9	6.36	15.44	16.24	**16.46**
Fingerprint Image 10	9.01	**36.01**	**24.73**	**15.77**

B. *Validation from a Fingerprint Perspective*

In this second part of validation, the tests compare the proposed CS fingerprint enhancement technique to a traditional gray scale fingerprint enhancement technique, the one proposed in [3]. It is based on the use of all together local *histogram equalization*, *Weiner filtering* and *binarisation.* The comparison is summarized in Table 3.

First, HE is replaced with the cuckoo search enhancer. Then, the comparison takes place by calculating the detected number of edges within the enhanced fingerprint images. This factor is used to compare the detail content level of the resulting images where the image with the highest number of edges are best ranked for having higher detail content [38].

TABLE 3 COMPARING THE NUMBER OF EDGES FOR THE HE AND THE PROPOSED CS

	Technique proposed in [3]		*The proposed CS*	
	Number of detected edges	*Number of real minutiae*	*Number of detected edges*	*Number of real minutiae*
Fingerprint Image 1	4823	167	**5103**	**259**
Fingerprint Image 2	3520	61	**3856**	**62**
Fingerprint Image 3	4283	**135**	**4473**	109
Fingerprint Image 4	3828	122	**3972**	**130**
Fingerprint Image 5	4270	**71**	**4620**	55
Fingerprint Image 6	3841	129	**4129**	**171**
Fingerprint Image 7	3850	102	**3854**	**167**
Fingerprint Image 8	1859	79	**2158**	**100**
Fingerprint Image 9	5085	97	**5780**	**121**
Fingerprint Image 10	4127	58	**4461**	**76**

In addition, as fingerprint enhancement techniques are validated [39] [40], this paper includes the number of real minutiae within each enhanced image considering both techniques to be compared. This work considers the number of real minutiae as a measure of comparison; it represents the number of all detected minutiae minus the spurious ones. The two parameters, the number of the detected edges and the number of the real minutiae are seen to come together to prove the efficiency of the CS gray level enhancer.

It is clear from the table that the images from Fig. 5 show a concrete enhancement in terms of ridge structure evidence and global quality. In addition, Table 3 shows that the number of edges increases using the proposed CS algorithm in all the ten cases, where it shows an improvement of 8 out of 10 cases, concerning the success of minutiae detection process.

From the obtained numerical results from Table 3, it is also obvious that the use of the CS algorithm within the enhancement method [3] outperforms its original state. This is mainly due to the continuity of ridges and the detection of new ones offered by the proposed approach. Edges are well detected. Hence minutiae are well positioned since the number of ridges increases, and so fingerprints are optimally represented. As shown, the enhancement process affects the processing phase, and the optimal templates representation will definitely affect the matching phase.

CONCLUSION

Traditional fingerprint enhancement techniques as most filtering and pixel intensity methods are very time consuming. In this context, this paper uses a CS algorithm for contrast enhancement of gray-scale fingerprint images. This approach is based on gray level mapping where the optimal new set of gray levels is metaheuristically obtained using the CS process with modified objective function to get the best fingerprint image quality.

The proposed approach has been tested on a set of gray-scale fingerprint images of poor quality gotten from the FVC2000 database. The results demonstrate the efficiency of the proposed approach both qualitatively and numerically, compared to state-of-the-art enhancers.

As future direction of research, the authors plan tackling further steps of the fingerprint recognition system with the use of the proposed CS image enhancer, to statistically check its impact on the whole process.

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