

Palmprint Identification Using Dolphin Optimization

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Abstract

Palm print recognition is a rapidly evolving area in the field of biometrics, providing a high level of security for various applications. Advances in scanning technology and software have led to faster and more accurate palm print analysis, we have proposed in this paper a system for palm recognition using the Dolphin Optimization Algorithm (DOA) as a computational technique inspired by nature aimed at solving complex improvement problems. We reduced the number of image features using the Histograms of oriented gradients (HOG) algorithm, we named this method as (DOA) and we also proposed a hybrid method by integrating the DOA algorithm with the Support Vector Machine (SVM) model to improve prediction accuracy by combining DSA's ability to search for global optimal solutions with the effective classification capabilities of SVM, this allows The hybrid approach creates a robust and the proposed hybrid method was named (SVM-DOA), and we also proposed a hybrid method by integrating the DOA algorithm with fuzzy c – mean (FCM) and we named the proposed hybrid method (DOA-fuzzy membership), we verified the validity of the proposed method on public database images of palm print. experiment show that the average accuracy rate of the dolphin swarm algorithm (DSO) is (96.8%), while the average accuracy rate of the proposed hybrid algorithm (DSO-SVM) is (97.8%), and the average accuracy of the proposed hybrid algorithm (DSO-fuzzy membership) is (98.1%).

Keywords

palm print, feature extracts, HOG algorithm, dolphin optimization algorithm, support vector machine, fuzzy c-mean

1 Introduction

Over the past years, researchers have set out to find safer and more accurate ways using biometrics that depend on the physiological or specific behavioral characteristics that the user possesses. Using a password to verify people's identity is not enough for correction and authentication because it contains many restrictions such as theft, loss or forgetfulness [1, 2]. Where studies and research have proven that the palm print of any person is unique, featured, interesting and remains constant and does not change throughout the life span of a lifetime. Human formation begins in the third month during embryonic development and is completed by the eighteenth week [3, 4]. Palm fingerprinting as a biometric identification method has many advantages over other traditional identification methods such as passwords, PINs or even other forms of biometrics Like fingerprints or facial recognition one of the main features is the larger surface area of the palm which offers a greater number of unique identification features, resulting in increased accuracy and reduced false match rates making it the preferred choice for diverse

applications such as access control, identity verification and even criminal investigations. As technologies continue to evolve, handprint recognition is predicted to perform a more vital role in ensuring the security and authenticity of individual identities [5–7].

The mechanism of identifying the palm print can be summarized in general in four stages:

1. Preparing the data either through a scan of the palm or from a database containing images of the palm print;
2. The stage of processing images or data in order to get rid of unnecessary parts and preserve the important parts in the image;
3. The stage of extracting properties in order to extract features such as lines, hills, wrinkles;
4. Matching the images of the data stored in the database in advance with the extracted data [8, 9].

In this paper, we will introduce the mechanism of palm recognition using the dolphin optimization algorithm that

involves collecting samples of palm print images and processing them to extract the relevant features. These features are then introduced into the DOA algorithm that uses different optimization techniques to search for the optimal feature set, once the optimal subset is identified, the algorithm assigns a score to each feature based on its contribution to the overall handprint recognition process.

2 Review of literature

Many works in the literature employ AI to recognize humans using Palm Print methods these works are mentioned below.

Cenys et al. in 2013 suggested a new palm print recognition method that used the GA as a recognition method that does not need any special equipment and can be used in fast palm recognition for identity management and personal authentication. This method is faster by 10 times more than the manual methods, the manual method requires 220 seconds while this method required only 25 seconds or less with the same accuracy which was 96% by using CASIA Dataset [10].

In 2014 Bebis and Amayeh developed a classification system based on the person's gender by finding the ratio between the wide to the height of the palm. This classification system consisted of two major steps: the image features extraction and the classification step using Polynomial Smooth Support Vector Machine (PSSVM). This method has 85% classification accuracy by using 180 images taken from 30 subjects [11].

In 2017 Meraoumia et al. introduced a new method using deep learning to extract features in two steps by (PCA) and four classifiers (RFT, KNN, SVM and RBF) this suggested system is named as (PVANet) this method gives good results comparing with the new works that reach 98% by testing PolyU dataset [12].

In 2018 Zhong et al. proposed a new method on the handprint by building a strong convolutional network based on a strong artificial network Deep Convolutional Neural Networks (DCNN) where you learn high-level skills through advanced exercises to move through a robust structure and the SVM classifier that takes advantage of feature vectors extracted by the modified Inception_ResNet_v1 network as samples This proposal was identified as (PalmRCNN) and this system was tested on the group (12000) dataset (image Palm fingerprint the results were specifically shown according to the percentage of 95.48% [13].

In 2018 Tarawneh et al. presented a new method using the convolutional neural network (CNN) to recognize the

palm print, and to extract features from the image using networks (Alex Net, VGG-16 and VGG-19) that have been previously trained, and a vector support machine (SVM) is used to carry out the classification process, and the proposed technique gave good results and this system was tested on a standard dataset (PolyU) and the results showed that the identification accuracy reached (95%) [14].

In 2019 Genovese et al. presented a new handprint recognition proposal called PalmNet, a convolutional network that classifies unsupervised data from multiple databases using Gabor filters, a PCA algorithm, and a 1-NN classifier based on Euclidean distance. This system was trained using (600) palm print images from the standard dataset (PolyU), and the results showed a rating accuracy of (95%) [15].

In 2021 Wu et al. proposed a new exploratory method to identify palm print by extracting three types of features, which are the most important components of the palm print image These features are the type of texture, the type of gradient and the type of direction, these three features are then combined to perform palm print matching, the system was tested on three palm-print dataset (CASIA, IITD, GPDS) The results showed a classification accuracy of (88%, 88% and 87%) respectively [16].

In 2021 Mustafa et al. presented a new method for identifying palm print using the Gaussian distribution calculation method based on the harmony search algorithm (HSA), where the proposed method consists of three main stages (training, testing, and recognition), which are trained through two stages: The first stage is the initial processing, which consists of many sub-stages (hash, ROI, and edge detector) and the second stage is extracting features from palm print images. Through the use of the Consistent Search Algorithm (HSA), this proposed system was tested on the standard dataset PolyU for palm print images and the results showed a classification accuracy of (92.60%) [17].

In 2022 Rajeshwari and Rathika proposed the introduction of a novel palm texture and form feature-based palm recognition method. Two techniques are used to extract these properties. Grayscale Co-occurrence Matrix (GLCM) is used in the first to extract texture data, and Laplacian or Gaussian functions are used in the second to extract shape features, which may be used to quantify matching accuracy and detect Euclidean space edges in images. The method has been evaluated against the PolyU dataset, and the GLCM method has a 74% accuracy rate while the shape method has an 80% accuracy rate [18].

In 2022 Wu et al. proposed Palmprint Fuzzy Commitment (FC) is based on DHC. On the basis of DHC,

a palmprint FC is suggested. The suggested palmprint FC can balance accuracy, memory usage, and computational complexity in a way that strikes a satisfying balance between DHC's high precision, small size, strong robustness, and lack of misalignment problem in the shift matching problem. Additionally, conducting bit selection based on uniqueness analysis and cascading the DHC of multispectral palmprints both increase accuracy. The EER can approach 0.0001% when the B, N, and R spectra are fused and only 292 bits are chosen, according to sufficient experimental findings [19].

In 2023, according to a novel research approach put out by Attia et al., characteristics from 2D and 3D palm prints can be extracted using BSIF and GIST descriptors, respectively. The feature vector's dimension can then be decreased using the PCA+LDA method. Next, cosine distance is used to complete the fitting process. The final matching score is then obtained by applying score-level fusion using a fuzzy linking technique based on a linear combination of triangular norms (t-norm and t-conorms). The suggested approach is also contrasted with a number of score fusion methods, such as triangle norm-based symmetric sum, Sum, Min, and Max. The method is compared against a publicly accessible database of 2D and 3D palm prints from Hong Kong Polytechnic University, and the findings demonstrate the effectiveness of the suggested system [20].

In 2023 Abdullah et al. proposed a new way to recognize palm print by combining right and left hand print images to obtain the optimal recognition rate where 2 iter (MMLOF) is used to extract features and to combine right and left hand print images fusion is used at the feature level and then extract the optimal MMOF features through optimization techniques such as particle swarm optimization (PSO) and genetic algorithm (GA) Finally, the PSO and GA optimization algorithms were wrapped with the nearest neighbor (NN) to evaluate the 2 fitness function, this proposed system was tested on the standard database IITD from palm print images and the results showed a classification accuracy of (96.95%) [21].

In 2023 Kumar and Kumar proposed a method for palm recognition using two classification algorithms Novel ResNet50 and X Gradient Boosting, where a comparison was made between the algorithms ResNet50 and X Gradient Boosting using a sample size of 10 per algorithm, which led to a total sample size of 20, and according to the results of the study, ResNet50 is more effective in accurately identifying biometric palm fingerprints compared to the Gradient

Boosting X algorithm. The statistical analysis of this study was carried out using IBM SPSS, this proposed system was tested on the database of palm print (BMPD) collected from the kaggle warehouse, which includes a total of 1640 images containing the fingerprints of the right and left hand, and according to the results, the ResNet50 algorithm achieved the highest rating accuracy rate of (94.7%) compared to the X Gradient Boosting algorithm, in which the classification accuracy reached (92.4%) [22].

In 2023 AlShemmary and Ameen in the Department of Computer Science and Mathematics at the University of Kufa in Najaf presented a new method of palm recognition based on the Siamese network, where the proposed approach consists of two convolutional neural networks (CNNs) that share weights and are trained to extract features from palm fingerprint images, which are then compared using the contrast loss function to determine whether the two images belong to the same person or not. The researchers also added that the performance of the detection system is stable and fast and is especially useful in cases where there are large numbers of categories and the network does not need to be retrained when adding, the data was divided into 20% for testing, and 80% for training was tested and implemented the proposed system using the palmprint database (CASIA Palmprint) had an equal error rate of 0.044 with an accuracy rating of 95.6% [23].

3 Proposed approach

Fig. 1 illustrates the proposed system of palm print recognition consisting of four steps:

1. Pre-processing of data to reduce dimensions;
2. Extract features from input images using the Histograms of oriented gradients (HOG) algorithm;
3. Entering the extracted data into the classification algorithm Dolphin Swarm algorithm;
4. Carry out the matching process after which the final This matched result is used to make the final decision. (User selected or not).

3.1 Preprocessing of the image

The process of processing images is of great importance in improving the images entered into the system, as it contributes to the preparation of data in an appropriate and appropriate manner for the subsequent stage, which in turn contributes to the process of identifying people, and the process of conducting a preliminary processing of the entered images includes two stages:

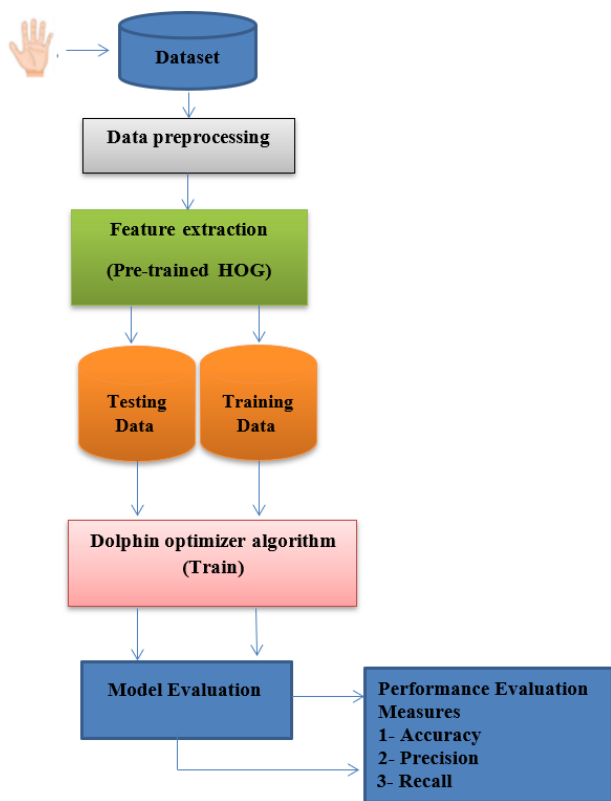


Fig. 1 Flowchart of the proposed system work steps

1. The first stage: make the image size (128 × 128).
2. The second stage: converting images from color images (RGB) to gray images (Gray) because the gray image is easier in the processing process compared to color images, which makes dealing with images in the work more convenient implemented using Open CV cv2.resize (color. rgb2gray) in (Python).

3.1.1 Palm print database

The dataset (Dataset Palm print) was obtained from the Internet at the site [24], which includes (2000) images belonging to fifty people at a rate of (40) different hand movements size (128 × 128) of the type (JPG) as the number of image samples is (2000) images for the training and testing processes These pictures of fifty people, each person has forty different hand movements, as 1500 images were adopted to train the system and 500 images to test the system to distinguish people according to their palm print. Fig. 2 shows public database of palm print images.

3.2 Feature extraction

One of the problems facing excellence algorithms is the presence of duplicate and unnecessary qualities that cause an increase in the volume of data and thus an increase in the research space to solve the problem, which leads to

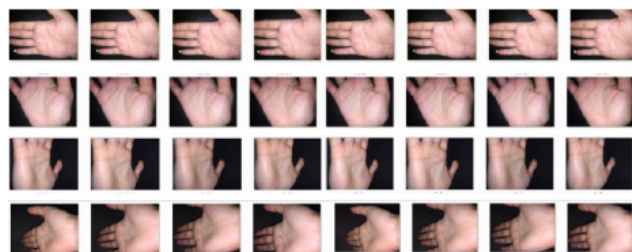


Fig. 2 A public database of palm print images

an increase in the time required for processing the data required for detection and classification [25, 26]. Here we will use the Histograms of oriented gradients (HOG) algorithm to extract traits that extracting traits from the image is one of the most important stages necessary for image processing and used the Histogram of Directed Gradient (HOG) algorithm to extract important traits from the image to benefit from them in the classification process and reduce the size of the data and thus reduce the time required to make classification [27, 28].

Basic stages of the HOG algorithm [29]:

1. The value of the gradient is found through the following steps:
 - Calculate the value of the gradient size per pixel using the following equation:

$$G(x, y) = \sqrt{G_x(x, y)^2 + G_y(x, y)^2}$$
 - Find the angle of gradient for each pixel through the following equation:

$$\theta(x, y) = \arctan\left(\frac{G_y(x, y)}{G_x(x, y)}\right)$$
2. We segment the picture into a block (2 × 2) with an overall 4 blocks.
3. Nine-way HOG extraction per block.
4. Grouping HOG blocks into a one-dimensional vector feature.

Fig. 3 is a diagram showing the use of the HOG algorithm to extract features from palm print images.

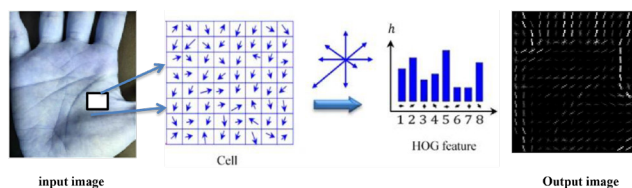


Fig. 3 Image chart of using the HOG algorithm to extract features from palm print images

In this work, traits were extracted based on the selection of the most important features that capture the highest amount of information about the data set. As the most important features are obtained by choosing and determining the number of (HOG – cell size) and HOG – block size). HOG technology was applied in Python using the library (from skimage. feature) (from import hog).

3.3 Dolphin optimization algorithm

Dolphin swarm optimization is a new computational method inspired by the cooperative hunting behavior observed in dolphins. This algorithm inspired by biology in nature has gained traction in recent years due to its efficiency in solving complex optimization problems across different domains relying on the inherent intelligence and agility of dolphins [30]. The dolphin optimization algorithm has gained great interest in the field of optimization algorithms due to its unique approach and successful applications in solving complex problems. This algorithm draws inspiration from the social behavior of dolphins, especially their collaboration and communication techniques. By imitating the way dolphins move around and interact with each other, dolphins are known as one of the smartest marine animals and have many interesting things including their biological characteristics and living habits that deserve attention, including echolocation, cooperation and division of labor among them, exchanging information and communicating with each other and communicating with each other in a certain language, especially during the predation process.

The dolphin optimization algorithm is able to explore the search space efficiently, making it a powerful tool for finding optimal solutions. Moreover, this algorithm incorporates exploration and exploitation strategies, allowing it to strike a balance between effectively exploring new solutions and exploiting the best solutions found [31].

The algorithm simulates the dynamics of its natural range to repeatedly search and adapt to the solution space as a result, dolphin flock optimization provides a unique and powerful tool to handle challenging optimization tasks with Providing valuable insights into the underlying mechanisms of animal social behavior [32, 33]. the basis of DOA consists of a location update equation, a speed update equation, and the use of echo positioning to determine the optimal solution. Through the use of these mechanisms, the algorithm seeks to navigate through the search space efficiently, adapting to possible changes in the problem of optimization and convergence to the optimal global level while avoiding local Optima traps [34, 35].

3.3.1 Main equations of dolphin optimization algorithm

The most important equations used in the dolphin optimization algorithm are expressed through the following steps:

1. Initial positioning method:

Create a community of dolphins randomly (proposed solutions) in the algorithm, spreading in search of prey.

2. The way of chasing after the prey:

Here dolphins work to update their speed and positions using the following equations:

$$\begin{aligned} Vel_{i,j}^{n+1}(t+1) &= w \times Vel_{i,j}^n(t) \\ &+ C1 \times r1 \times \left(\left(P_{best\ i,j}^n \right) - X_{i,j}^n(t) \right) \\ &+ C2 \times r2 \times \left(\left(G_{best\ i,j}^n \right) - X_{i,j}^n(t) \right), \end{aligned} \quad (1)$$

$$X_{i,j}^{n+1}(t+1) = X_{i,j}^n(t) + Vel_{i,j}^{n+1}(t+1), \quad (2)$$

whereas $Vel_{i,j}$ represents the speed of the dolphin; $X_{i,j}$ represents the position of the dolphin n at moment i ; $P_{best\ i,j}^n$ represents the best solution that the dolphin has reached so far (the subjective part); $G_{best\ i,j}^n$ is the best solution recorded within the dolphin swarm (collective part) is represented; $C1$, $C2$ are the coefficients representing acceleration values; W is the coefficient representing the weight of inertial; n represents the number of cycles.

3. Attacking the prey:

The goal that dolphins seek behind is to approach and then attack the sardine groups and then eventually prey on them, if these dolphins are constantly chasing the group of sardines for some time, they will catch up with the swarm or reach useful sites where they can prey on the group of sardines. However, according to our assumptions, dolphins only use a rotary swimming position to move when they attack or prey on a group of sardines.

If we assume that a group of dolphins is constantly chasing a group of sardines within time steps t ($t < Gen$), some of these dolphins have reached useful locations where they can prey or attack a group of sardines according to this case, we update the locations according to Eqs. (3) and (4) to shoot the scene:

$$X_{i,m}^{n+1}(t+1) = r_{R,l}, \quad (3)$$

$$X_{i,m}^{n+1}(t+1) = r_{i,l}, \quad (4)$$

where $r_{R,l}$ is a uniformly distributed random number in the interval; $r_{i,l}$ is a uniformly distributed random number in the interval; l is a random number

belonging to the group ($n...1$); t is the time step; Gen is the maximum number of iterations ($m...1$).

4. Switch swimming modes:

At this stage, the dolphins dynamically change to swimming mode and can use different swimming positions according to (their needs survival and foraging instinct). At this stage, we calculate the value of (Y) according to the following equation:

$$X_{i,j}^k = 1/2(X_{i,j}^k(t)), \quad k = 1, \dots, A, \quad (5)$$

where A is the size of the dolphin community.

We arrange Y_j in ascending order. Let's assume that Y_j is ranked in $O_j(t)$ out of each Y according to ascending sorting and then we evaluate μ :

$$\mu_{i,j}^k(t) = (O^k(t) - 1) / A. \quad (6)$$

Here is a value μ representing the worth of the switch (either attack mode or chase mode) [36, 37] as shown in Algorithm 1.

3.3.2 Classification steps using the dolphin optimization algorithm (DOA)

The classification here is done using the dolphin optimization algorithm through the following steps:

1. Initialize a set of parameters such as community size A , coefficients W , $C2$, $C1$, Gen maximum number of iterations, W time steps ($T = 1$).
2. The primary community is generated randomly.
3. Evaluation of the fitness function for all members of the group by using a correlation relationship between the matrix of all data (train, test) and the target matrix as shown by the following equation:

$$\text{Fitness} = \frac{\sum_p \sum_q (M_{pq} - \bar{M})(N_{pq} - \bar{N})}{\sqrt{\sum_p \sum_q (M_{pq} - \bar{M})^2} \times \sqrt{\sum_p \sum_q (N_{pq} - \bar{N})^2}},$$

where M represents the image matrix and its size ($p \times q$), and N represents the target matrix and its size ($p \times q$).

4. We increase T one step in time.
5. This stage includes the following:
 If $t \leq \omega$ we update the dolphin locations according to Eqs. (1) and (2) and then evaluate the whether the new solutions are superior to the previous ones, we update.
 For solutions and adopting the best solution.

If $t > \omega$ we calculate the value of y and arrange it ascending using the Eq. (5) and then calculate the value of the switch μ for all dolphins using Eq. (6) and give f random values confined between (0–1) and if $\mu \leq f$ we update the sites according to the Eqs. (3) and (4).

Then evaluate the new solutions, if the new solutions perform better than the previous ones, we update the solutions and adopt the best solution.

6. The condition for stopping will be either when the desired solution is reached or the number of preset cycles has expired, otherwise I will go to step 4.

3.3.3 Pseudo-codes of the (DOA) algorithm

The pseudo-codes of Algorithm 1, which better illustrates the steps of the proposed method.

3.4 Proposed hybrid method (DOA-SVM)

Machine is one of the supervised learning algorithms used in regression problems and classification, it uses classification for its effectiveness and excellent accuracy, with regard to the supporting vector machine (SVM) classifier the selection of optimal parameters is of great importance to achieve high performance in biometric identification systems [38, 39]. Key parameters associated with SVM include G (gamma), E (epsilon) and C . Optimizing

Algorithm 1 Pseudo-codes of the (DOA) algorithm

```

Begin
Step 1: Initialization. Set the maximum generation  $Gen$ , dimension  $n$ , parameter  $W$ ,  $C1$ ,  $C2$ ,  $\omega$ . Set the generation counter  $t = 1$ 
Step 2: Initialize the population of dolphins
Step 3:  $t = t + 1$ 
Step 4: While the best solution is not found or  $t < Gen$  do
Step 5:   If  $t \leq \omega$ 
Step 6:     Each dolphin uses Eqs. (1) and (2) to update its position
Step 7:     Evaluation the population according to the newly update positions
Step 8:   Else
Step 9:     For  $j = 1$  to  $A$  (for all dolphins) do
Step 10:      The  $j$  the dolphin uses Eq. (5) to calculate  $Y_j$ 
Step 11:    End for  $j$ 
Step 12:    Sort all the dolphin individuals according to these  $Y_j$ 
Step 13:    For  $j = 1$  to  $A$  (for all dolphins) do
Step 14:      Each dolphin uses Eq. (6) to calculate its switching factor  $\mu_j$ 
Step 15:      Select a random number  $\text{rand} \in [0,1]$ 
Step 16:      If  $\mu_j \leq \text{rand}$  and
Step 17:        The  $j$  the dolphin uses Eqs. (3) and (4) to update its position
Step 18:      Else
Step 19:        The  $j$  the dolphin uses Eqs. (1) and (2) to update its position
Step 20:      End if
Step 22:    End for  $j$ 
Step 23:    End if
Step 24:    Evaluation the population according to the newly update positions
Step 25:     $t = t + 1$ 
Step 26:  End while
End
    
```

the selection process for these parameters within an SVM classifier is critical to enhancing the overall effectiveness and reliability of palm recognition systems [40, 41].

The integration of the Dolphin Swarm algorithm and Support Vector Machine provides a unique perspective to improve the problem-solving and classification process, harnessing the strengths of both methodologies. These algorithms can adapt together collaboratively and intelligently to efficiently find global optimal solutions and accurately predict outcomes, thereby improving the overall performance of the model. Investigating the specific elements and mechanisms within this shared approach can foster a better understanding of the interaction between the two algorithms and their contributions to problem solving. Furthermore, delving into the challenges and potential improvements of this innovative integration presents opportunities for future developments in optimization and classification techniques as shown in Algorithm 2.

Algorithm 2 Pseudo-codes of the (DOA-SVM) algorithm

Step 1: Initialization. Set the maximum generation Gen , dimension n , parameter $W, C2, C1, \omega$; Set the generation counter $t = 1$
 Step 2: Initialize the population of dolphins by C, E, G with between maximum and minimum value for parameters of SVM
 Step 3: Objective function as fitness (C, E, G) from Dolphin data from step 4 to 7
 Step 4: Train the (SVM) with (train data)
 Step 5: Get the SVM predict with test data
 Step 6: Calculate mean squared error between predict data and test data
 Step 7: Fitness evaluation by MSE. Evaluate each dolphin according to its position
 Step 8: $t = t + 1$
 Step 9: While the best solution is not found or $t < Gen$ do
 Step 10: If $t \leq \omega$
 Step 11: Each dolphin uses Eqs. (1) and (2) to update its position
 Step 12: Evaluation the population according to the newly update positions
 Step 13: Else
 Step 14: For $j = 1$ to M (for all dolphins) do
 Step 15: The j the dolphin uses Eq. (5) to calculate Y_j
 Step 16: End for j
 Step 17: Sort all the dolphin individuals according to these Y_j
 Step 18: For $j = 1$ to A (for all dolphins) do
 Step 19: Each dolphin uses Eq. (6) to calculate its switching factor μ_j
 Step 20: Select a random number $rand \in [0,1]$
 Step 21: If $\mu_j \leq r$ and
 Step 22: The j the dolphin uses Eqs (3) and (4) to update its position
 Step 23: Else
 Step 24: The j the dolphin uses Eqs. (1) and (2) to update its position
 Step 25: End if
 Step 26: End for j
 Step 27: End if
 Step 28: Evaluation the population according to the newly update positions
 Step 29: $t = t + 1$
 Step 30: End while
 End

3.4.1 Classification steps using the proposed hybrid method (DOA-SVM)

The classification here will be done with the same classification steps using the Dolphin Optimization Algorithm (DOA) in Section 3.3.2, except for the change of the fitness function, which is formed through the following steps:

1. Taking the current dolphin values and placing them within the (SVM) parameters (C, E and G) and building (SVM-model) based on dolphin values.
2. Function Training (SVM) with Overall examination data.
3. Inspection (SVM-model) with test data.
4. Calculate the squared sum of errors between the examination data and the output (SVM-model) and this the current dolphin rating is considered.

The pseudo-codes of the proposed hybrid algorithm which better illustrates the steps of the proposed method.

3.4.2 Pseudo-codes of the (DOA-SVM) algorithm

Algorithm 2 is the pseudo-codes of the algorithm which better illustrates the steps of the proposed method.

3.5 Proposed hybrid method (DSO-fuzzy membership)

Unclear sets and unclear membership scores are concepts used in mathematics and computer science to represent uncertainty. Traditional groups contain elements that are partial or not partial of the group, while obscure groups allow partial membership. This is useful when dealing with situations where the line between belonging and non-belonging is not well defined. [42, 43] Ambiguity is a term that describes something that is not easily recognizable or recognized that is often used in situations where there is no clear answer or is difficult to classify. Ambiguous membership expresses the degree to which something belongs to a particular class or group, where exact definitions are required but not always possible [44, 45].

In this paper we proposed to combine the DSO algorithm and the Fuzzy C-mean algorithm in order to improve the dolphin swarm optimization algorithm, by combining these two techniques we can get more accurate models of the behavior of dolphin swarms and better understand how to improve their movements leading to more accurate predictions by allowing partial membership, the algorithm becomes more flexible and can better adapt to the unique aspects of each individual palm print. In addition, the integration of fuzzy membership in Process optimization in

mitigating errors caused by incomplete data or noise in the system. The equation for fuzzy membership:

$$\mu_{ij} = \left[\sum_{k=1}^c \left(\frac{d_{ij}}{d_{ik}} \right)^{\frac{2}{h-1}} \right]^{-1}, \quad (7)$$

where μ_{ij} is between 0 and 1; c is the centroids of cluster i ; $d_{ij} = x_i - v_i$ represents Euclidean Distance between i^{th} . The data set has N data objects $\{x_1, \dots, x_j, \dots, x_N\}$.

Then, each cluster is associated with a P -dimensional prototype vector $v_1 = \{v_{11}, \dots, v_{12}, \dots, v_{1p}\} \in \mathfrak{R}^p$; c_i is the data point; $h \in [1, \infty]$ is a weighting exponent which is a real number greater than 1.

3.5.1 Classification steps using the proposed hybrid method (DSO-fuzzy membership)

The classification here is done using the same classification steps used in the dolphin optimization algorithm (DOA) in Section 3.3.2 with the addition of the Eq. (7) for the membership score to the equation of updating locations (Eq. (2)) in the dolphin optimization algorithm.

3.5.2 Pseudo-codes of the (DSO-fuzzy membership) algorithm

The Pseudo-codes of the new algorithm is the same as the Pseudo-codes of the dolphin optimization algorithm (DSO) with the modification of (Step 6) and (Step 19) and the addition of the fuzzy membership equation to the equation of updating locations as follows:

- Step 6: Each dolphin uses Eqs. (1), (2) and (7) to update its position.
- Step 19: The j the dolphin uses Eqs. (1), (2) and (7) to update its position.

3.6 System performance assessment measures

In this research, we adopted the evaluation of the proposed system (DOS), (DOS-SVM) and (DOA-fuzzy membership) to identify people through their palm print on a set of standard standards, where the system's effectiveness was assessed using (Confusion Matrix) based on the standards of accuracy), sensitivity, and specificity, the measures of assessing performance of the system in the Python language were calculated using the import library (confusion matrix) as follows [46, 47]:

1. Accuracy: It represents the percentage of correct predictions in the system:

$$\text{Accuracy} = TP / (TP + FP) \times 100.$$

2. Sensitivity Scale (Recall): Measures the ability of the classification system to find faulty palm print images:

$$\text{Sensitivity (Recall)} = TP / (TP + FN) \times 100.$$

3. Specificity: Measures the system's ability to find the correct palm print images:

$$\text{Specificity} = TP / (TP + FP) \times 100.$$

3.7 Algorithm training and testing phases

At this stage, work has been done to train the dolphin optimization algorithm (DSO) as well as the proposed hybrid method (DOA -SVM) and the hybrid method (DSO-fuzzy membership) by entering 1500 images of the palm print by entering the traits matrix extracted from the training images of the input images, after which the initial processing of the images and extraction of traits is carried out by using the Histograms of oriented gradients (HOG) algorithm for training images. The extracted trait matrix is then entered into the dolphin swarm optimization algorithm (DSO) as well as the method. Proposed hybrids (DOA-SVM) and hybrid method (DSO-fuzzy membership).

After completing the training phase and the stability of the algorithm, it is tested by entering 500 images of palm print, preprocessing the entered images, then extracting the characteristics from them using the Histograms of oriented gradients (HOG) algorithm. The process of determining special coefficients and assigning them to each algorithm is based on the type of work in which the specific transactions may differ according to the problem that the researcher is working to find a solution to after conducting a set of practical experiments and applying them and choosing the appropriate ones, the values of the coefficients for the algorithms used have been reached the values of the coefficients have been set as shown in Table 1.

The data was trained in the (DOS) system to identify the palm print, which consists of 1500 images of the palm

Table 1 The hyperparameter used in the proposed system

Hyper parameter	Choice
Split dataset	75%, test 25%, train
Number of classes	50
HOG – block size	2
HOG – cell size	32, 16, 8
C1	$2 \times (1 - \text{iter}/\text{max_iter})$
C1	$-1 + \text{iter} \times ((-1)/ \text{max_iter})$
W	$2 \times (1 - \text{iter}/\text{max_iter})$
Initial population of Dolphin	30, 40
Max no. iteration	50, 30
Image size	128×128

print, and the results of the proposed algorithm training were obtained according to the evaluation scales and the results appeared as follows:

$$\begin{aligned} \text{Sensitivity(Recall)} &= 100\%, (FN) = 0, (FP) = 0, \\ TN &= (1500), (\text{Accuracy}) = 100\%, \\ (\text{Precision}) &= 100\%. \end{aligned} \tag{8}$$

The data was tested in the (DOS) system to identify the palm print, which consists of 500 images of the palm print, and the results of the training of the proposed algorithm were obtained as shown in Table 2.

Table 2 shows the results of the test phase of the Dolphin algorithm (DOS) when the values of the coefficients are as (HOG – cell size) at (8, 16, 32), (HOG – block size) at (2), Population of Dolphin at (10, 30, 50) and (Max no. iteration) at (10, 30, 50).

The data was trained in the (DOS-SVM) system to identify the palm print, which consists of 1500 images of the palm print, and the results of the training of the proposed hybrid algorithm were obtained according to the evaluation scales, the results appeared as follows:

$$\begin{aligned} \text{Sensitivity(Recall)} &= 100\%, (FN) = 0, (FP) = 0, \\ TN &= (1500), (\text{Accuracy}) = 100\%, \\ (\text{Precision}) &= 100\%. \end{aligned} \tag{9}$$

The data is tested in the (DOS-SVM) system to identify the palm print, which consists of 500 images of the palm print, and the results were obtained as shown in Table 3.

Table 3 shows the results of the test phase in the proposed hybrid method (DSO-SVM) when the values of the coefficients are as (HOG – cell size) at (8, 16, 32), (HOG – block size) at (2), Initial, (population of Dolphin) at (10, 30, 50) and (Max no. iteration) at (10, 30, 50).

The data was trained in the system (DOS-fuzzy membership) to identify the palm print, which consists of 1500 images of the palm print, and the results of the training of the proposed algorithm were obtained according to the evaluation scales and the results appeared as follows:

$$\begin{aligned} \text{Sensitivity(Recall)} &= 100\%, (FN) = 0, (FP) = 0, \\ TN &= (1500), (\text{Accuracy}) = 100\%, \\ (\text{Precision}) &= 100\%. \end{aligned} \tag{10}$$

The data was tested in the (DOS-fuzzy membership) system to identify the palm print, which consists of 500 images of the palm print, and the results of the algorithm training were obtained Proposed as shown in Table 4.

Table 4 shows the results of the test phase in the proposed hybrid method.

DOA-fuzzy membership when the values of the parameters are as (HOG – cell size) at (8, 16, 32), (HOG – block

Table 2 System results in testing

Exp. No.	HOG – cell size	HOG – block size	Initial population of dolphin	Max no. iteration	Accuracy (%)	Processing time (second)
1	8	2	10	10	92.1%	11.965
2	8	2	30	30	93.6%	12.105
3	8	2	50	50	94.2%	12.950
4	16	2	10	10	93.2%	7.077
5	16	2	30	30	93.4%	7.290
6	16	2	50	50	94.2%	7.920
7	32	2	10	10	96.8%	5.100
8	32	2	30	30	93.4%	5.210

Table 3 System results in testing

Exp. No.	HOG – cell size	HOG – block size	Initial population of dolphin	Max no. iteration	Accuracy (%)	Processing time (second)
1	8	2	10	10	93.2%	5.869
2	8	2	30	30	94.4%	6.101
3	8	2	50	50	95.6%	6.311
4	16	2	10	10	94.8%	1.445
5	16	2	30	30	94.0%	1.498
6	16	2	50	50	95.6%	1.530
7	32	2	10	10	97.8%	1.039
8	32	2	30	30	94.8%	1.287

Table 4 System results in testing

Exp. No.	HOG – cell size	HOG – block size	Initial population of Dolphin	Max no. iteration	Accuracy (%)	Processing time (second)
1	8	2	10	10	93.6%	4.965
2	8	2	30	30	94.8%	5.105
3	8	2	50	50	96.0%	6.210
4	16	2	10	10	95.8%	1.077
5	16	2	30	30	95.0%	1.107
6	16	2	50	50	96.2%	1.202
7	32	2	10	10	98.1%	0.201
8	32	2	30	30	95.8%	0.218

Table 5 Dolphin Swarm Algorithm Accuracy Ratio Rate (DSO), Proposed Hybrid Method (DSO-SVM) and Proposed Hybrid Method (DOS-fuzzy membership)

Accuracy rate	The number of images used in testing	Nmae of the model	Processing time (second)
96.8%	500	Dolphin Optimization (DSO) Algorithm	5.100
97.8%	500	Dolphin Optimization Algorithm With SVM (DSO-SVM)	1.039
98.1%	500	Dolphin Optimization Algorithm with Fuzzy C-mean (DOS-fuzzy membership)	0.201

size) at (2), (Initial population of Dolphin) at (10, 30, 50) and (Max no. iteration) at (10, 30, 50)

Table 5 shows the rating ratio rate of the Dolphin Swarm Algorithm (DSO) and the proposed hybrid method (DSO-SVM) and the proposed hybrid method (DSO-fuzzy membership).

3.8 Experimental results

The experiment results revealed that the classification ratio of the (DOA) algorithm and the proposed hybrid algorithm (DSO-SVM) and the proposed hybrid algorithm (DSO-fuzzy membership) reached (100%) for the training phase, the results contained in Table 2 showed that the best classification accuracy was achieved on images with a size of (128 × 128) equal to (96.8%) and a cell size of (32 × 32). When the number of dolphins was equal to the number of repetitions, the results in Table 3 showed that the best classification accuracy was achieved on images with a size of (128 × 128) equal to (97.8%) and a cell size of (32 × 32) when the number of dolphins was equal to the number of repetitions, the results in Table 4 showed that the best classification accuracy was achieved on images with a size of (128 × 128) equal to (98.1%) and a cell size of (32 × 32) when the number of dolphins was equal to the number of repetitions, looking at Table 5 The results of the experiment show that the average accuracy rate of the dolphin swarm algorithm (DSO) is (96.8%), while the average accuracy rate of the proposed hybrid algorithm (DSO-SVM) is (97.8%), and the average accuracy of the proposed hybrid algorithm (DSO-fuzzy membership) is (98.1%).

We note through experiments that the proposed hybrid algorithm (DOS-SVM) has improved the rate of classification ratio compared to the dolphin swarm algorithm (DOS), and the reason is due to the optimization algorithm Dolphin Swarm that simulates the cooperative behavior of dolphins to improve the process of selecting parameters with its unique ability to adapt and learn from its previous configurations, DSA accelerates the rate of convergence which reduces computational expenses. Thus, a well-tuned DSA strikes a balance between exploration and exploitation, fine-tuning these parameters ensures optimal performance while maintaining the simplicity of the model. Thus, the selection of appropriate parameters enhances the rate of DSA convergence.

We note through experiments that the proposed hybrid algorithm (DOS-fuzzy membership) has improved the rate of classification ratio compared to the dolphin swarm algorithm (DOS) and the proposed hybrid algorithm (DOS-SVM) and the reason is that the algorithm (Fuzzy C-mean) and Dolphin swarm (Optimization) are two complementary technologies that can improve their effectiveness when used together in practice Combining the two algorithms can lead to better results in terms of aggregation and classification tasks compared to using either algorithm separately specifically. The opaque C means algorithm provides soft aggregation capabilities allowing for a more accurate classification of certain data points especially those that tend to have overlapping features. At the same time, the dolphin optimization algorithm can provide powerful search capabilities that can help identify specific data points more

Table 6 Comparing the search result with the most recent methods used

No.	Authors	Year	Methods	Dataset	Recognition accuracy
1	Cenys et al. [10]	2013	Genetic algorithm based palm recognition method for biometric authentication systems	CASIA	96%
2	Amayeh et al. [11]	2014	Hand-based gender classification	180 images	85%
3	Meraoumia et al. [12]	2017	Improving Biometric Identification Performance using PCANet Deep Learning and Multispectral Palmprint	PolyU	98%
4	Zhong et al. [13]	2018	Palmprint and Palmvein Recognition Based on DCNN and a New Large-Scale Contactless Palmvein Dataset	(12000) palm print images	95.48%
5	Tarawneh et al. [14]	2018	Pre-trained Convolutional Neural Networks CNNs to extract features and then (SVM) used for classification	PolyU	95.5%
6	Genovese et al. [15]	2019	PalmNet–GaborPCA	PolyU	95%
7	Wu et al. [16]	2021	Triple-Type Feature Extraction for Palmprint Recognition	CASIA	88%
				IITD	88%
				GPDS	87%
6	Mustafa et al. [17]	2021	Palm print recognition based on harmony search algorithm	PolyU	92.60%
9	Rajeshwari and Rathika [18]	2022	Palm Print Recognition Using Texture and Shape Features	PolyU	74%
				GLCM	80%
10	Wu et al. [19].	2022	A multi-spectral palmprint fuzzy commitment based on deep hashing code with discriminative bit selection	CASIA Palm print	95.4%
11	Attia et al. [20]	2023	A fuzzy connective score fusion technique for 2D and 3D palmprint authentication system	PolyU	93.8%
12	Abdullah et al. [21]	2023	A Single Objective GA and PSO for the Multimodal Palmprint Recognition System	IITD	96.95%
13	Kumar and Kumar [22]	2023	Accurate Biometric Palm Print Recognition Using ResNet50 algorithm Over X Gradient Boosting Algorithm	BMPD	94.7%
					92.4%
14	AlShemmary and Ameen [23]	2023	Siamese Network-Based Palm Print Recognition Dolphin Optimization (DSO) Algorithm	CASIA Palm print	96.5%
				Public database	96.8%
15	This study	2024	Dolphin Optimization Algorithm With SVM (DSO-SVM)	Palm print	97.8%
				Dolphin Optimization Algorithm with Fuzzy C-mean (DOS-fuzzy membership)	98.1%

efficiently reducing computational load. Which contributes significantly to the overall performance and improvement of the rate of classification accuracy as shown in Table 6.

In this paper, we proposed a system for palm recognition using the Dolphin Improvement Algorithm (DOA) and achieved a classification accuracy of (96.8%) with a processing time of (5.100) seconds, and we proposed a new hybrid algorithm by combining the algorithms (DOA) and the (SVM) algorithm to improve the classification accuracy by forming a new fitness function based on the (SVM) algorithm that will depend on the values of dolphins instead of their original parameters (G, E, C) and achieved classification accuracy of (97.8%) with a processing time

of (1.039) seconds, and we proposed another new hybrid algorithm by merging two algorithms (DOA) with the algorithm (Fuzzy C-mean) to improve classification accuracy by adding Eq. (7) of (membership) to Eq. (2) of changing positions in the algorithm of dolphin (DOA) by allowing partial membership and processing uncertainty in the data. The algorithm is able to better deal with uncertain and inaccurate data, which leads to Establishing a more accurate identification system and achieving higher classification accuracy compared to the dolphin algorithm (DOA) and the (DSO-SVM) algorithm, where the classification accuracy reached (98.1%) with a processing time that took (0.201) seconds.

3.9 Experimental environment

The training equipment used in this article includes an eight-core Intel i6 processor, an NVIDIA1060 graphics card, and 16 GB of memory, and the programming language is Python 3.5.2 [48].

4 Comparison table

Here we will make a comparison between previous studies of the latest methods used with the results obtained in our research, the Table 6 shows Comparing the search result with the most recent methods used.

5 Conclusion

As the field of artificial intelligence continues to develop, palm recognition is becoming an increasingly important aspect of biometric technology. The use of the Dolphin optimization algorithm has proven to be a promising and important method to improve the accuracy and efficiency of handprint recognition, enabling artificial intelligence systems to recognize and verify people based on handprint patterns. By integrating this technology with AI systems, companies are able to improve their security measures and reduce the risk of unauthorized access, this article highlights the relationship between Dolphin Swarm algorithm parameters and SVM parameters, providing valuable insights into its effectiveness and the ability to adjust it to improve classification results. By combining the ability of DSA to search for globally optimal solutions with the efficient classification capabilities of SVM, improvements in parameter selection will play an important role in further improving the accuracy and durability of palm recognition systems, leading to the development of better-understood systems. Strength and security contribute significantly to the reliability of biometric systems, and this hybrid approach creates robust and powerful models

References

- [1] Amraoui, A., Fakhri, Y., Kerroum, M. A. "Multispectral Palmprint Recognition based on Fusion of Local Features", In: 2018 6th International Conference on Multimedia Computing and Systems (ICMCS), Rabat, Morocco, 2018, pp. 1–6. ISBN 978-1-5386-6221-2 <https://doi.org/10.1109/ICMCS.2018.8525989>
- [2] Hamidi, A., Khemgani, S., Bensid, K. "Transfer Learning Using VGG Based on Deep Convolutional Neural Network For Finger-Knuckle-Print Recognition", In: Proceedings of the 2nd International Conference on Computer Science's Complex Systems and their Applications (ICCSA'2021), Oum El Bouaghi, Algeria, 2021, pp. 25–26. ISBN 978-3031026195 [online] Available at: <https://ceur-ws.org/Vol-2904/38.pdf> [Accessed: 08 February 2024]
- [3] Brown, D., Bradshaw, K. "Improved Palmprint Segmentation for Robust Identification and Verification", In: 2019 15th International Conference on Signal-Image Technology and Internet-Based Systems (SITIS), Sorrento, Italy, 2019, pp. 1–7. ISBN 978-1-7281-5686-6 <https://doi.org/10.1109/SITIS.2019.00013>
- [4] Li, Q., Dong, P., Zheng, J. "Enhancing the Security of Pattern Unlock with Surface EMG-Based Biometrics", Applied Sciences, 10(2), 541, 2020. <https://doi.org/10.3390/app10020541>

in terms of processing time and accuracy. model in terms of processing time and accuracy.

This paper proves that the combination of dolphin swarm algorithm and fuzzy C-Mean algorithm brings higher recognition accuracy through the efficient search ability of dolphin swarm algorithm and the algorithm and ability of fuzzy C-mean to process overlapping data points. The hybrid algorithm shows improvements in assembly accuracy and efficiency. Overall, the combination of these two technologies brings the possibility of accurate pattern recognition and individual identification.

6 Recommendation

Looking at the future of palmprint recognition there are many potential areas of research:

1. By 2025, around 1.4 billion users are expected to utilize biometric identification technologies to authenticate payments, instead of swiping a payment card, users can simply present their biometric identity to verify payments. The software is already available in five Brazilian locations, and the company aims to roll it out globally at a later date.
2. Looking at the future of palm recognition using the dolphin optimization algorithm, there are many potential areas of research One way is to explore the use of this algorithm along with other biometric data sources, such as facial recognition, fingerprint recognition, iris or other biometric recognition methods.
3. Another area of research is to investigate the scalability of this algorithm to larger palm print databases in addition to that the potential impact of environmental factors such as lighting or humidity on the accuracy of this algorithm when applied to palm recognition can be investigated.

- [5] Chen, S., Liu, Y., Gao, X., Han, Z. "MobileFaceNets: Efficient CNNs for Accurate Real-time Face Verification on Mobile Devices", In: *Biometric Recognition: 13th Chinese Conference*, Urumqi, China, pp. 428–438, 2018. ISBN 978-3-319-97908-3
https://doi.org/10.1007/978-3-319-97909-0_46
- [6] Meena, G., Choudhary, S. "Biometric authentication in internet of things: A conceptual view", *Journal of Statistics and Management Systems*, 22(4), pp. 643–652, 2019.
<https://doi.org/10.1080/09720510.2019.1609722>
- [7] Rida, I., Al-Maadeed, N., Al-Maadeed, S., Bakshi, S. "A comprehensive overview of feature representation for biometric recognition", *Multimedia Tools and Applications*, 79(7), pp. 4867–4890, 2020.
<https://doi.org/10.1007/s11042-018-6808-5>
- [8] Fei, L., Zhang, B., Xu, Y., Guo, Z., Wen, J., Jia, W. "Learning Discriminant Direction Binary Palmprint Descriptor", *IEEE Transactions on Image Processing*, 28(8), pp. 3808–3820, 2019.
<https://doi.org/10.1109/TIP.2019.2903307>
- [9] Zhang, Y., Zhang, L., Liu, X., Zhao, S., Shen, Y., Yang, Y. "Pay by Showing Your Palm: A Study of Palmprint Verification on Mobile Platforms", In: *2019 IEEE International Conference on Multimedia and Expo (ICME)*, Shanghai, China, pp. 862–867, 2019. ISBN 978-1-5386-9552-4
<https://doi.org/10.1109/ICME.2019.00153>
- [10] Cenys, A., Gibavicius, D., Goranin, N., Marozas, L. "Genetic Algorithm Based Palm Recognition Method for Biometric Authentication Systems", *Elektronika ir Elektrotechnika*, 19(2), pp. 69–74, 2013.
<https://doi.org/10.5755/j01.eee.19.2.3473>
- [11] Bebis, G., Amayeh, G., U.S. Patent and Trademark Office "Hand-based gender classification", Washington, DC, USA, US8655084B2, 2014. [online] Available at: <https://patents.google.com/patent/US8655084B2/en> [Accessed: 18 February 2014]
- [12] Meraoumia, A., Kadri, F., Bendjenna, H., Chitroub, S., Bouridane, A. "Improving Biometric Identification Performance Using PCANet Deep Learning and Multispectral Palmprint", In: Jiang, R., Al-maadeed, S., Bouridane, A., Crookes, D., Beghdadi, A. (eds.) *Biometric Security and Privacy: Opportunities & Challenges in The Big Data Era*, Springer, 2017, pp. 51–69. ISBN 978-3-319-47300-0
https://doi.org/10.1007/978-3-319-47301-7_3
- [13] Zhong, D., Yang, Y., Du, X. "Palmprint Recognition Using Siamese Network", In: *Biometric Recognition: 13th Chinese Conference (CCBR 2018)*, Urumqi, China, 2018, pp. 48–55. ISBN 978-3-319-97908-3
https://doi.org/10.1007/978-3-319-97909-0_6
- [14] Tarawneh, A. S., Chetverikov, D., Hassanat, A. B. "Pilot Comparative Study of Different Deep Features for Palmprint Identification in Low-Quality Images", [preprint] arXiv:1804.04602, 10 April 2018.
<https://doi.org/10.48550/arXiv.1804.04602>
- [15] Genovese, A., Piuri, V., Plataniotis, K. N., Scotti, F. "PalmNet: Gabor-PCA Convolutional Networks for Touchless Palmprint Recognition", *IEEE Transactions on Information Forensics and Security*, 14(12), pp. 3160–3174, 2019.
<https://doi.org/10.1109/TIFS.2019.2911165>
- [16] Wu, L., Xu, Y., Cui, Z., Zuo, Y., Zhao, S., Fei, L. "Triple-Type Feature Extraction for Palmprint Recognition", *Sensors*, 21(14), 4896, 2021.
<https://doi.org/10.3390/s21144896>
- [17] Mustafa, R. A., Chyad, H. S., Haleot, R. A. "Palm print recognition based on harmony search algorithm", *International Journal of Electrical & Computer Engineering (IJECE)*, 11(5), pp. 4113–4124, 2021.
<https://doi.org/10.11591/ijece.v11i5.pp4113-4124>
- [18] Rajeshwari, M., Rathika, K. "Palm Print Recognition Using Texture and Shape Features", *International Journal of Computer Science and Engineering*, 9(2), pp. 1–5, 2022.
<https://doi.org/10.14445/23488387/IJCSE-V9I2P101>
- [19] Wu, T., Leng, L., Khan, M. K. "A multi-spectral palmprint fuzzy commitment based on deep hashing code with discriminative bit selection", *Artificial Intelligence Review*, 56(7), pp. 6169–6186, 2023.
<https://doi.org/10.1007/s10462-022-10334-x>
- [20] Attia, A., Hammouche, R., Akhrouf, S., Akhtar, Z. "A fuzzy connective score fusion technique for 2D and 3D palmprint authentication system", *Evolving Systems*, 14(5), pp. 891–901, 2023.
<https://doi.org/10.1007/s12530-022-09477-7>
- [21] Abdullah, M., Kedir, B., Alemayehu, K. A., Habtemariam, H. T. "A Single Objective GA and PSO for the Multimodal Palmprint Recognition System", *Mathematical Problems in Engineering*, 2023, 7621550, 2023.
<https://doi.org/10.1155/2023/7621550>
- [22] Kumar, H. K., Kumar. S. A. "Accurate Biometric Palm Print Recognition Using ResNet50 algorithm Over X Gradient Boosting Algorithm", In: *E3S Web of Conferences, International Conference on Newer Engineering Concepts and Technology (ICONNECT-2023)*, Tiruchirappalli, Tamil Nadu, India, 2023, 04027.
<https://doi.org/10.1051/e3sconf/202339904027>
- [23] AlShemmary, E., Ameen, F. A. "Siamese Network-Based Palm Print Recognition", *Journal of Kufa for Mathematics and Computer*, 10(1), pp. 108–118, 2023.
<https://doi.org/10.31642/JoKMC/2018/100116>
- [24] Izadpanahkakhk, M. "Sapienza University Mobile Palmprint Database:SMPD", [online] Available at: <https://www.kaggle.com/datasets/mahdieizadpanah/sapienza-university-mobile-palmprint-databasesmpd> [Accessed: 03 September 2019]
- [25] Soranamageswari, M., Meena, C. "Statistical Feature Extraction for Classification of Image Spam Using Artificial Neural Networks", In: *2010 Second International Conference on Machine Learning and Computing*, Bangalore, India, 2010, pp. 101–105. ISBN 978-1-4244-6006-9
<https://doi.org/10.1109/ICMLC.2010.72>
- [26] Vithlani, P., Kumbharana, C. K. "Structural and Statistical Feature Extraction Methods for Character and Digit Recognition", *International Journal of Computer Applications*, 120(24), pp. 43–47, 2015.
<https://doi.org/10.5120/21413-4451>

- [27] Moen, U. "Early Detection of Alzheimer's Disease using 3D Texture Features and 3D Convolutional Neural Networks from structural MRI", MSc Thesis, University of Stavanger, 2018. [online] Available at: <http://hdl.handle.net/11250/2564781> [Accessed: 08 February 2024]
- [28] Cetina, K., Márquez-Neila, P., Baumela, L. "A Comparative Study of Feature Descriptors for Mitochondria and Synapse Segmentation", In: 2014 22nd International Conference on Pattern Recognition, Stockholm, Sweden, 2014, pp. 3215–3220. ISBN 978-1-4799-5209-0
<https://doi.org/10.1109/ICPR.2014.554>
- [29] Elhariri, E., El-Bendary, N., Hassaniien, A. E., Snael, V. "An Assistive Object Recognition System for Enhancing Seniors Quality of Life", *Procedia Computer Science*, 65, pp. 691–700, 2015.
<https://doi.org/10.1016/j.procs.2015.09.013>
- [30] Wu, T.-q., Yao, M., Yang, J.-h. "Dolphin swarm algorithm", *Frontiers of Information Technology & Electronic Engineering*, 17(8), pp. 717–729, 2016.
<https://doi.org/10.1631/FITEE.1500287>
- [31] Gholizadeh, S., Poorhoseini, H. "Seismic layout optimization of steel braced frames by an improved dolphin echolocation algorithm", *Structural Multidisciplinary Optimization*, 54(4), pp. 1011–1029, 2016.
<https://doi.org/10.1007/s00158-016-1461-y>
- [32] Soto, R., Crawford, B., Carrasco, C., Almonacid, B., Reyes, V., Araya, I., Misra, S., Olguín, E. "Solving Manufacturing Cell Design Problems by Using a Dolphin Echolocation Algorithm", In: *Computational Science and Its Applications – ICCSA 2016: 16th International Conference*, Beijing, China, 2016, pp. 77–86. ISBN 978-3-319-42092-9
https://doi.org/10.1007/978-3-319-42092-9_7
- [33] Yong, W., Tao, W., Cheng-Zhi, Z., Hua-Juan, H. "A New Stochastic Optimization Approach — Dolphin Swarm Optimization Algorithm", *International Journal of Computational Intelligence Applications*, 15(2), 1650011, 2016.
<https://doi.org/10.1142/S1469026816500115>
- [34] Wu, T., Yao, M., Yang, J. "Dolphin Swarm Extreme Learning Machine", *Cognitive Computation*, 9(2), pp. 275–284, 2017.
<https://doi.org/10.1007/s12559-017-9451-y>
- [35] Kaveh, A., Hoseini Vaez, S. R., Hosseini, P. "Modified Dolphin Monitoring Operator for Weight Optimization of Frame Structures", *Periodica Polytechnica Civil Engineering*, 61(4), pp. 770–779, 2017.
<https://doi.org/10.3311/PPci.9691>
- [36] Sharma, S., Kaul, A. "Hybrid fuzzy multi-criteria decision making based multi cluster head dolphin swarm optimized IDS for VANET", *Vehicular Communications*, 12, pp. 23–38, 2018.
<https://doi.org/10.1016/j.vehcom.2017.12.003>
- [37] Qiao, W., Yang, Z. "Modified Dolphin Swarm Algorithm Based on Chaotic Maps for Solving High-Dimensional Function Optimization Problems", *IEEE Access*, 7, pp. 110472–110486, 2019.
<https://doi.org/10.1109/ACCESS.2019.2931910>
- [38] Qi, Z., Tian, Y., Shi, Y. "Robust twin support vector machine for pattern classification", *Pattern Recognition*, 46(1), pp. 305–316, 2013.
<https://doi.org/10.1016/j.patcog.2012.06.019>
- [39] Shao, Y.-H., Zhang, C.-H., Wang, X.-B., Deng, N.-Y. "Improvements on Twin Support Vector Machines", *IEEE Transactions on Neural Networks*, 22(6), pp. 962–968, 2011.
<https://doi.org/10.1109/TNN.2011.2130540>
- [40] Shao, Y.-H., Deng, N.-Y., Yang, Z.-M. "Least squares recursive projection twin support vector machine for classification", *Pattern Recognition*, 45(6), pp. 2299–2307, 2012.
<https://doi.org/10.1016/j.patcog.2011.11.028>
- [41] Kapri, A. "Everything one should know about - Support Vector Machines (SVM)", Medium, 23 February 2020. [online] Available at: <https://medium.com/analytics-vidhya/everything-one-should-know-about-support-vector-machines-svm-18e6d3f96f49> [Accessed: 23 February 2020]
- [42] Mendel, J. M., Bonissone, P. P. "Critical Thinking About Explainable AI (XAI) for Rule-Based Fuzzy Systems", *IEEE Transactions on Fuzzy Systems*, 29(12), pp. 3579–3593, 2021.
<https://doi.org/10.1109/TFUZZ.2021.3079503>
- [43] Chimatapu, R., Hagra, H., Starkey, A., Owusu, G. "Explainable AI and Fuzzy Logic Systems", In: *Theory and Practice of Natural Computing*, Dublin, Ireland, 2018, pp. 3–20. ISBN 978-3-030-04069-7
https://doi.org/10.1007/978-3-030-04070-3_1
- [44] Shukla, A. K., Smits, G., Pivert, O., Lesot, M.-J. "Explaining Data Regularities and Anomalies", In: *2020 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, Glasgow, UK, 2020, pp. 1–8. ISBN 978-1-7281-6933-0
<https://doi.org/10.1109/FUZZ48607.2020.9177689>
- [45] Ferreyra, E., Hagra, H., Kern, M., Owusu, G. "Depicting Decision-Making: A Type-2 Fuzzy Logic Based Explainable Artificial Intelligence System for Goal-Driven Simulation in the Workforce Allocation Domain", In: *2019 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, New Orleans, LA, USA, 2019, pp. 1–6. ISBN 978-1-5386-1729-8
<https://doi.org/10.1109/FUZZ-IEEE.2019.8858933>
- [46] Chicco, D., Jurman, G. "The advantages of the Matthews correlation coefficient (MCC) over F1 score and accuracy in binary classification evaluation", *BMC Genomics*, 21(1), 6, 2020.
<https://doi.org/10.1186/s12864-019-6413-7>
- [47] Memon, M. H., Li, J., Haq, A. U., Memon, M. H. "Early Stage Alzheimer's Disease Diagnosis Method", In: *2019 16th International Computer Conference on Wavelet Active Media Technology and Information Processing*, Chengdu, China, 2019, pp. 222–225. ISBN 978-1-7281-4243-2
<https://doi.org/10.1109/ICCWAMTIP47768.2019.9067689>
- [48] Python "Python, 3.5.2", [online] Available at: <https://www.python.org/downloads/release/python-352/> [Accessed: 27 June 2016]