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Artificial bee colony-based nonrigid demons registration

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ABSTRACT

The artificial bee colony (ABC) algorithm has gained popularity in recent years for its ability to solve optimization problems. The accuracy and resilience of ABC-based image processing techniques have demonstrated encouraging outcomes. The ABC method is an excellent solution for image processing issues since it has the ability to swiftly and effectively explore the search space. The current research intends to address image registration issues by refining the existing image registration strategy using ABC algorithm. The process of nonrigid demons registration is frequently employed in the processing of medical images. The combination of these two techniques is referred to as the ABC-based nonrigid demons registration method. The proposed method has shown superior performance in registration accuracy and efficiency compared to other existing methods. Applications in medical image analysis and computer-assisted diagnosis are highly promising for the ABC-based nonrigid demons registration. Particle swarm optimization (PSO) and frameworks based on genetic algorithms (GA) have been compared with the suggested framework. The observed results showed improved accuracy and faster convergence in ABC-based demons registration.

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1. INTRODUCTION

With the rapid growth of image processing in the medical sciences, remote sensing, and computer vision, the need for powerful transformation methods such as image fusion and image registration has emerged as a key area for researchers. The image registration technique is a manual or automated method that seeks to locate similar areas between two photographs and spatially align [1] them to reduce the desired inaccuracy, i.e., a consistent assessment of proximity between the two images. Finding conformity between two photos such that all of their points line up is known as image registration. Specifically, the values of each pixel in the referred and sensed images were compared. Images may have been taken at various times, from various views or angles, using various sensors or equipment, and then the various datasets may have been combined [2] into a single coordinate system. The image [3] that serves as the foundation for all subsequent image transformations and alignments with respect to it is known as the referenced image. There are many applications for image registration, including cartography, computer vision, weather forecasting, environmental monitoring, change detection, image mosaicking, and the production of higher resolution images. Medical imaging applications include computed tomography (CT) and magnetic resonance imaging (MRI) to monitor tumor growth and for treatment verification.

One could say that the act of computing spatial transforms that align a collection of photographs to a single common observational frame of reference, often one of the images in the collection, is known as image registration. Any image analysis or understanding assignment that requires combining data from several sources requires registration as a crucial step. Two situations emerge throughout the registration process: it is impossible to imagine, it is a matching problem, and it takes the longest amount of time to run the algorithm. The three-dimensional information of one of the images needs to be transformed for it to be associated with the image that was selected as its reference in terms of its coordinate system. Two applications for image registration are possible: i) Image-to-image registration: to combine or integrate two or more images that depict the same objects, corresponding pixels must be aligned; ii) Image-to-map registration: in this case, the input image is warped while retaining its original spatial resolution to match the map information of a base image.

It is commonly used in medical and satellite photography to align images from various camera sources. Digital cameras employ the image registration technique to align and connect nearby photos to create a single panoramic image. Every technique of image registration must go through the same four key processes to align the images. These could include the following: i) Feature detection: a domain expert can identify obtrusive and recognizable items (e.g., closed boundary areas, edges, contours, line intersections, corners) in both the reference and target images; ii) Feature matching: this demonstrates how the features in the reference and felt images are related. The matching strategy is based on the symbolic description of the control point set or the content of the image; iii) Estimation of transformation: aligning the detected image with the reference image requires the calculation of the parameters and type of what are known as mapping functions; iv) Resampling and transformation: utilizing mapping functions, the observed image is modified.

Image registration can be rigid or nonrigid depending on the transformation and how it affects the objects in the image. Rigid body registration, which involves aligning images via rigid body transformation, such as rotation, scaling, translation, or a combination of these methods, is one of the most basic methods of image registration. Images can now be aligned with deformations using nonrigid registration techniques, which are gaining popularity. Image registration increasingly involves the use of multimodal imaging techniques, such as the integration of magnetic resonance (MR) and CT. Nonrigid registration can alter the shape of the items included in the image, making it usually malleable. Diffusion frequently aids the algorithm in morphing the image's objects, but it also causes distortion of the image's objects. Due to its straightforward implementation and linear computing complexity, Thirion's Demons is a widely used technique for nonrigid image registration. The force vectors that cause the deformation toward alignment are repeatedly estimated, and they are smoothed using Gaussian convolution to address the diffusions in the registration.

An improved registration procedure decreases errors, improves image quality, and increases the precision of upcoming research. The ability to more effectively compare, track, and combine images aids in object detection, motion estimation, and image stitching. The selection of optimization parameters and algorithms is key to the quality of the registration. Nonuniform deformations and distortions, which might be prevalent in some types of photographs, can be overcome via optimization. The registration accuracy can be impacted by variations in image quality, sampling, and noise, which can be considered via optimization [4]. Overall, picture registration must be optimized to provide dependable and efficient use for a variety of applications, including remote sensing, surveillance, and scientific research, as well as medical diagnosis, monitoring, and treatment planning. The collective intelligence and adaptability of natural systems, such as genetic evolution, ant colonies, and swarm behavior, serve as the inspiration for metaheuristic algorithms, which are optimization approaches [5]. Bioinspired optimization algorithms use the concepts of adaptation, learning, and self-organization to solve complicated problems by modelling biological processes. Algorithms for optimization that use metaheuristics and bioinspired principles are frequently used in a wide range of fields, including machine learning, control systems, image processing, and engineering design. Metaheuristic optimization techniques include genetic algorithms, simulated annealing, particle swarm optimization, and ant colony optimization, whereas bioinspired optimization methods include neural networks, evolutionary tactics, and artificial immune systems. The ability of metaheuristic [6] and bioinspired optimization algorithms to solve complex problems with high dimensionality, nonlinearity, multimodality, and uncertainty and to find nearly optimal solutions in a reasonable amount of time with minimal computational overhead can be attributed to their popularity. The metaheuristic optimization algorithm known as the artificial bee colony (ABC) algorithm was used to model the foraging strategy of honeybees. To effectively traverse the search space and identify the best solution, the ABC algorithm imitates how bees forage for food. The ABC algorithm offers certain distinct advantages over other optimization techniques of a similar nature. After honey bees forage, the ABC algorithm excels at solving difficult optimization problems. The inclusion of neighborhood search strategies and their ability to establish a balance between exploration and exploitation increase the quality of the solution and accelerate convergence. The ABC algorithm's ease of parameter management, straightforward implementation, and capacity for handling noisy and dynamic environments further make it a desirable choice for a range of real-world optimization applications. The ABC algorithm has been successfully applied to various optimization [7] problems, including parameter tuning, feature selection, clustering, and image processing. For optimization tasks, the ABC algorithm [8], [9] was chosen since it strikes a balance between exploration and exploitation, allowing for quicker processing and better outcomes. It is useful for quickly reaching the best results because of its rapid search and exploration of the solution space. For a number of reasons, image registration process optimization is essential. First, it increases the precision with which various images are aligned, making comparisons and analyses more accurate. This is crucial for medical diagnosis since accurate alignment of medical pictures is needed to identify anomalies and monitor the course of disease. Second, optimization minimizes [10], [11] the computing time and resource requirements while improving the registration process's efficiency. This is advantageous in many domains where large datasets and real-time image processing [12] are typical, such as computer vision applications and remote sensing. The improvement of picture registration [13], [14] processes guarantees better outcomes, conserves time and resources, and permits more efficient use of image data for a variety of applications. Hence, the current work aims to optimize nonrigid demons registration using the ABC algorithm. The current work also uses particle swarm optimization (PSO) and genetic algorithms (GA) based approaches, as they have been used previously [15] in the demons registration framework, to compare the results of the ABC-based framework.

The remainder of this paper is organized as follows. Section 2 discusses related works on nonrigid image registration and optimizations using the ABC algorithm. Section 3 focuses on the materials and methods used in the current work. The proposed method is explained in section 4. Section 5 presents the results. The paper is concluded in section 6.

2. LITERATURE REVIEW

The associated research on ABC-based image registration includes a number of works with an emphasis on swarm intelligence, optimization methods, and medical image analysis. These papers investigated the progress of the optimization of image registrations in the current scenario and the efficacy of the ABC algorithm in enhancing the alignment and registration precision of medical pictures. Researchers have examined many ABC algorithm iterations, presented unique objective functions, and assessed how well ABC performs in comparison to other registration techniques. They demonstrated that a number of medical imaging activities can be accomplished using ABC-based image registration, such as tumor diagnosis, brain mapping, and image-guided procedures.

Thirion proposed image matching as a diffusion process in 1990, using Maxwell's demons [1] as an analogy. They proposed the idea of diffusion models in this study to carry out image-to-image matching. Currently, this algorithm is known as Thirion's Demons. Later, in 2005, Wang *et al.* [2] validated Thirion's demons as an expedited "demons" method for deformable image registration in radiation therapy. In this study, they used an "active force" and an adaptive force strength modification during the iterative process to speed up the method. The framework [6] developed by Wang *et al.* [2] was improved upon by Tang *et al.* [7] in 2016. By including a new parameter called the balancing coefficient in the active demons algorithm, the proposed method changes the driving force together with the homogeneity coefficient. The large deformation and the minor deformation were taken into account simultaneously, which helped to partially ease the mutual restraint problem of the convergence speed and the registration accuracy. A coarse-to-fine multiresolution method was added to the registration process to significantly increase the registration accuracy and convergence time while avoiding local extreme values. The ABC method was first introduced in 2007 by Karaboga and Basturk [3]. The performance of the ABC algorithm for limited optimization problems was compared in this paper using the extended bee colony approach [3]. The ABC algorithm and its applications were presented in 2012 by Abu-Mouti and El-Hawary [5]. They provided a summary of the literature in this paper and used the ABC algorithm as their approach to a solution. When it was first developed, the ABC algorithm was a population-based metaheuristic optimization method that was motivated by the clever foraging strategies of honeybee swarms. The salient attributes and performance traits of the ABC algorithm were also discussed. Pampará and Engelbrecht proposed binary ABC optimization in 2011 [6]. Three variations of ABC that allowed it to be used to solve optimization problems with binary-valued domains were proposed in this paper. A benchmark of unconstrained optimization problems was used to compare the performances of these binary ABC methods. The ABC algorithm was recently employed in 2021 by Vakilian *et al.* [8] in collaboration with the fog nodes in the internet of things three-layer architecture. In this study, a problem of optimization was proposed with the aid of fog nodes and clouds to strike a balance between the average reaction time and energy cost. The ABC [9] algorithm was used to resolve the proposed problem. The effectiveness of the method in enhancing alignment and registration accuracy was also highlighted by a literature survey. The current nonrigid demon registration system has the drawback of failing to appropriately account for the many traits and skills of demons. Effective identification and tracking are hampered by the incomplete and erroneous data produced by this lack of parameter adjustment. The method can be better adapted to fit the distinctive characteristics of various demons by adjusting the parameters, which boosts the overall effectiveness and dependability of the registration process. The potential of ABC-based registration in numerous medical imaging applications has been demonstrated by researchers who have investigated various optimization strategies and objective functions. To improve its performance and scalability, further research is needed. Additionally, it is clear that there is a lack of work involving the ABC algorithm to optimize the image registration framework.

3. METHOD

3.1. Artificial bee colony (ABC) algorithm

In recent years, many image processing problems have been solved by ABC optimization algorithms. An ABC is a swarm-based optimization technique. We use this ABC as the optimization technique for image and numerical problems. The ABC algorithm was inspired by the clever foraging behavior of honey bees. The algorithm is composed of three key components: employed bees, onlooker bees and scout bees [10]. The ABC algorithm is shown below [11].

```
Initialization Phase
    Repeat:
           Employee Bee Phase
                 Onlooker Bee Phase
           Scout Bee Phase
    Memories of the best solution achieved
The UNTIL stopping criterion is met.
```

Bee activities [12] are categorized into four phases, and there is an initialization phase after the main phase begins. In the first phase, each employee bee is assigned to different food resources or possible solutions. In the employee bee phase, each employee bee [13] is assigned to calculate the nectar amount of the food resource or good solution associated with it and its distance from the hive. The employee bees transmit the gathered information with the bees wait outside the hive after gathering it from the original source. The following stage involves the follower or spectator bees (the bees waiting in the hive) reading information about various food resources or potential solutions and selecting the best one. In the 3rd step, named the scout bee phase, the employee bees whose food resources or solutions become unavailable become scout bees. The main task of scout bees is to search for new solutions. In the field of computer image processing and image fusion, the ABC algorithm is used for optimization. It is a highly successful optimization technique used across the world. In medical image processing, the algorithm provides a satisfactory solution [4]. Therefore, the ABC optimization algorithm was also used for the image registration process.

3.2. Nonrigid demons registration

Among all the components of medical image analysis, picture registration is the most crucial. In medical image analysis, nonrigid registration is one of the key factors that requires both accuracy and efficiency to maintain the difference between the deformed query image and the reference image. For any nonrigid image registration, the number of demons is a vital factor. For any effective algorithm, demons play a vital role. Demons, in terms of computational models, uses some gradient information rather than directional information from medical images. Lan *et al.* [12] worked on nonrigid medical image registration using the image field in demons algorithms, which depicts a method using demons algorithms in the image field for processing medical images. Image spatial transformation in registration combines image fields with conventional model-based registration to determine the image's direction. Pennec *et al.* proposed 3D nonrigid demon registration by gradient descent. This paper addresses the increasing use of the Demons algorithm in the field of nonrigid medical image registration. In this paper, they reformulate Gaussian and physical models of regularization for minimization problems. Lin *et al.* [13] worked on an improved method of the Demons nonrigid image registration algorithm. This paper is mostly based on the optical flow of aspect in a demons nonrigid registration algorithm using force formulation. In certain scenarios, the force formulations have some lacuna in terms of topological structure that cannot be maintained throughout the entire deformation region. Mishra *et al.* [14] defined 2D/3D nonrigid image registration by an efficient demons approach. This paper depicts an aspect of nonrigid image registration by mapping the images into two groups, mostly models for future selection and models that work on image intensity by using the demons image field. In 2020, Chakraborty *et al.* [15] introduced gray wolf-based Wang's demons for retinal image registration. In the paper, they described three demons registrations that have been widely used in medical imaging. The original Demons algorithm was initially proposed by Thirion. Deformable picture registration can be solved using a traditional optimization strategy. The displacement of the deviator De between the target image (t) and the reference image (r) utilizes the iterative formula provided in (1).

$$De_{i,j}^{n} = De_{i,j}^{n-1} - \frac{(t_{i,j}^{n-1} - r_{i,j}^{0})\nabla r_{i,j}^{0}}{\left|\nabla r_{i,j}^{0}\right|^{2} + \left|\left(t_{i,j}^{n-1} - r_{i,j}^{0}\right)\right|^{2}} \tag{1}$$

for $i, j = 1, 2, 3, \ldots, N$. The following initial condition must be met for this equation to iterate:

$$\left.\begin{aligned} De_{i,j}^{0} &= 0 \\ t_{i,j}^{0} &= t_{i,j} \\ r_{i,j}^{0} &= r_{i,j} \end{aligned}\right\} \tag{2}$$

where $t_{i,j}$ and $r_{i,j}$ are the pixel-specific intensities of the original static and moving images, respectively, and N is any positive integer.

4. PROPOSED METHOD

The ABC technique [16], [17] effectively finds the ideal deformation field by treating the demons registration [18], [19] problem as an optimization task. The advantage of this method is that it aligns medical images more quickly and accurately, improving diagnosis and treatment planning. The ABC-based demons registration approach is a flexible tool for medical imaging research since it is simple to modify to handle multimodal or time-varying pictures. The registration framework [20], [21] and optimization framework [22]–[24] are shown in Figure 1. The current work uses a tennis video obtained from [25].

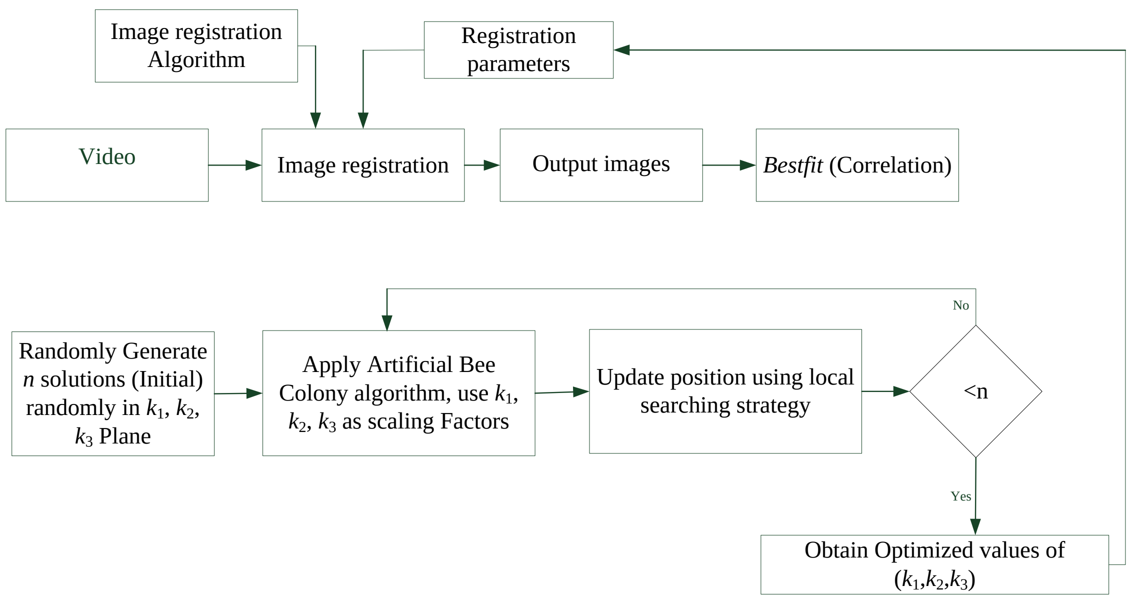

Figure 1. Artificial bee colony-based demons registration framework

Figure 1 demonstrates how the photos were initially taken from the video. The framework received the chosen monomodal images. The registration procedure used a flexible Demons registration structure. The ABC algorithm in the registration [20] framework is used to accomplish the optimization procedure. Particle swarm optimization [22]–[24] has been employed to compare the ABC framework in the current work in addition to the ABC algorithm. The scaling considerations in the current work include the window size and the sigma of the Gaussian filter in the demons registration. A Gaussian low-pass filter serves as a velocity field smoothing kernel in Thirion's Demons and Wang's Demons, with a sigma value of 10 (k_3) pixels and a window size (k_1, k_2) of 60×60. These values are used scaling factors (k_1, $k_{2,}$ and k_3).

5. EXPERIMENTAL RESULTS

The current research was evaluated and put into practice using an Intel i3 computer with a 2.2 GHz processor and MATLAB R2018a for picture registration, ABC, and particle swarm optimization. The correlation coefficient [14] is calculated by (2).

$$corr = \frac{\sum_a \sum_b (K_{ab} - K^{'})(L_{ab} - L^{'})}{\sqrt{(\sum_a \sum_b (K_{ab} - K^{'})^2)(\sum_a \sum_b (L_{ab} - L^{'})^2)}} \quad (2)$$

Table 1 reports the evaluation metrics and the three parameters to be optimized, namely, k_1, k_2 and $k_{3,}$ for the ABC-based data registration [26] framework. Previous works have shown that the population was fixed at 15, and the number of iterations changed from 5 and increased by 5 in each case study. A similar approach was taken in the current work. As shown in the Table 1, convergence was reached after the 15th iteration.

Table 1. Artificial bee colony-based results

Iteration × Population	Window size height (K_1)	Window size width (K_2)	Sigma (K_3)	Fitness value (Correlation)	Time taken (Seconds)
5 ×15	78	85	19	0.9063	4575.07
10 × 15	93	97	19	0.9162	9611. 90
15 × 15	96	79	19	0.9190	13471.27
20 ×15	96	96	20	0.9220	19414.65
25 × 15	96	96	20	0.9220	23637.68
30 × 15	96	96	20	0.9220	27154.15

The obtained images are shown in Figure 2. The figures show that the original image shown in Figure 2(a) is transformed into a registered image in Figure 2(b), and the registered image (with optimization) shown in the Figure 2(c) is quite close to the target image in Figure 2(d) compared to the registered image without optimization. The same can be observed in the table. The high correlation between the target Figure 2(d) and registered images in Figure 2(c) proves that the registration was quite accurate.

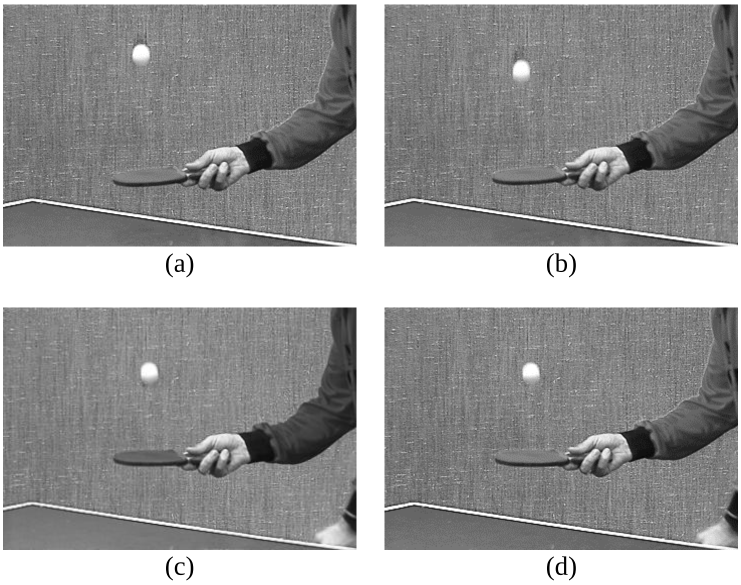

Figure 2. Effect of artificial bee colony-based demons registration (a) original image (frame 1), (b) registered image (without optimization), (c) registered image (with optimization), (d) target image (frame 8)

The particle swarm optimization-based results are shown in Table 2. The results showed that the procedure was slower than that of the ABC-based method. Additionally, the optimized results were also poor compared to those of the ABC algorithm. The genetic algorithm-based results are shown in Table 3. The results showed that the procedure was faster than the PSO-based framework as well as the ABC-based method. Furthermore, the optimized results were also poor compared to those of the PSO and ABC algorithms. However, the framework continued until the 35th iteration, compared to the PSO and ABC-based approaches, which converged after the 20th iteration.

Table 2. Particle swarm optimization-based results

Iteration × population	Window size height (k_1)	Window size width (k_2)	Sigma (k_3)	Fitness value (correlation)	Time taken (seconds)
5 ×15	60	61	12	0.7165	6336.56
10 × 15	84	75	16	0.8345	11367.65
15 × 15	95	98	13	0.9178	17463.71
20 ×15	96	96	16	0.9190	25147.47
25 × 15	96	96	16	0.9190	31461.28
30 × 15	96	96	16	0.9190	35144.48

Table 3. Genetic algorithm-based results

Iteration × population	Window size height (K_1)	Window size width (K_2)	Sigma (K_3)	Fitness value (Correlation)	Time taken (Seconds)
5 ×15	23	72	19	0.6299	121.54
10 × 15	56	59	17	0.7877	228.32
15 × 15	62	33	9	0.8369	345.85
20 ×15	97	54	10	0.8916	468.39
25 × 15	90	87	16	0.9014	564.14
30 × 15	92	92	17	0.9058	772.45
35 × 15	92	92	17	0.9058	943.47

To investigate the convergence of the GA-based framework, the system had to continue processing until the 35th iteration. Hence, despite being faster, the convergence speed was lower than that of the ABC- and PSO-based frameworks. The obtained fitness function values, i.e., the optimized values of both ABC-based demon registration and PSO-based demon registration, are shown in Figure 3. Figure 3 clearly shows that the ABC-based framework achieved better results.

As previously mentioned, the correlation between the target and registered image (with optimization) was set as the fitness function. Hence, the better correlation value establishes that the registration was more accurate in the ABC-based framework than in the PSO-based framework. The time complexity of both frameworks is analyzed through a line graph in Figure 4. Figure 4 clearly shows that the GA-based framework performed faster than the ABC and PSO-based frameworks. Although the ABC-based framework was superior in terms of stability and convergence, it achieved convergence in the optimization procedure faster than did the GA-based and PSO-based approaches. Additionally, it should be mentioned that as previously reported in Tables 2 and 3, in both frameworks, the convergence of scaling factors as well as the fitness value occurred in the 15th iteration.

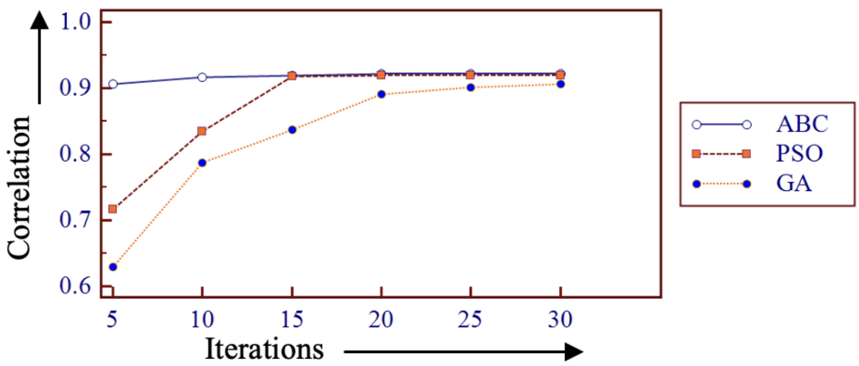

Figure 3. Comparative analysis of fitness values of ABC-based, PSO-based and GA-based demons registration

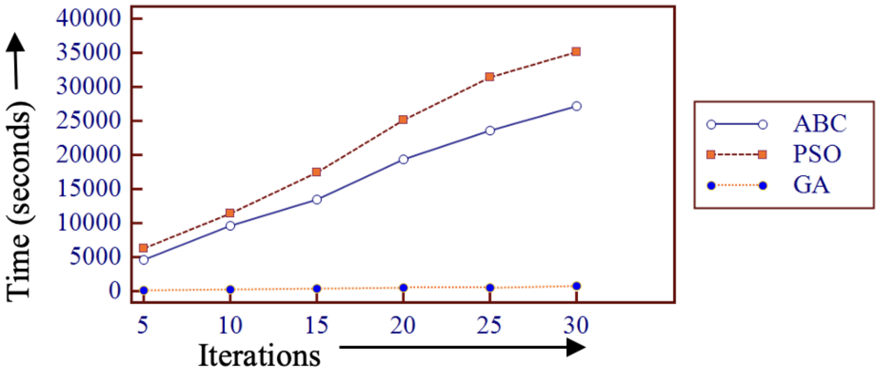

Figure 4. Comparative analysis of the time complexity of ABC-based, PSO-based and GA-based demon registration

6. DISCUSSION

The current study aimed to improve demon registration by optimizing its parameters. The current work uses ABC as an optimization algorithm for this purpose. The results shown in Tables 1 to 3 and Figures 2 and 3 show that ABC-based optimization significantly improved the demon registration procedure; the high correlation between the involved image and the registered image helps to confirm this finding. As highlighted in section 2, the optimization of image registration includes different methods, such as particle swarm optimization and genetic algorithms. The current work tries to find better results than the existing frameworks, which have been highlighted in the experimental results. Improving the image registration framework is necessary to reduce registration errors [26]. The current work also shows that ABC-based demons registration was significantly faster (as shown in Figure 3). A reduction in time will help researchers process larger datasets in minimal time if the image registration process [27], [28] is involved. The exploration-exploitation trade-off can be tailored using the flexibility of genetic algorithms to change the population size and selection pressure. They have advantages over PSO and ABC frameworks, which may have little control over exploration and exploitation tactics due to their versatility. Due to the balance between exploration and exploitation, genetic algorithms frequently show resistance to local optima. It is a faster technique than ABC or PSO because of its robustness, which enables it to quickly navigate challenging fitness landscapes and may outperform PSO and ABC frameworks that could more easily become stuck in local optima. Hence, it can be concluded from the above observation that for the monomodal framework, ABC-based demon registration converged faster than did the PSO and GA-based frameworks and provided better accuracy in terms of image registration.

7. CONCLUSION

To effectively align medical pictures, the ABC-based demonic registration approach combines the swarm intelligence of bees with the optimization powers of the ABC algorithm. The ABC algorithm looks for the best deformation field that minimizes the difference between the source and destination images by treating demon registration as an optimization assignment. The alignment of medical images, which is essential for precise diagnosis and treatment planning, has shown enhanced accuracy and speed. The results shown in Tables 1 to 3 and Figures 2 and 3 show that the ABC-based approach achieved better results. The higher correlation of the obtained images in the ABC-based approach supports the claim that the ABC-based registration was better in terms of performance than the GA-based and PSO-based approaches. However, the GA-based approach was faster (see Figure 3) than the ABC-based framework, despite producing poor results while optimizing the framework. The optimization of the registration framework has been performed previously, but the main aim of the study was to observe whether the ABC algorithm can effectively search the solution space and identify optimal solutions. The versatility, ease of use, and capacity to address intricate real-world issues of ABC render it a very desirable option for optimization across many fields, including image processing. The ABC-based demons registration method also has a number of benefits over conventional methods. It is a flexible tool for medical imaging research since it can readily handle multimodal or time-varying pictures. Strong and reliable registration results are ensured by the algorithm's capacity to search the solution space quickly and effectively while adjusting to various image properties. The registration process gains natural and logical quality from the ABC algorithm's inspiration from honeybee foraging behavior. It is a potent optimization technique for demon registration since it uses the colony's collective intelligence to find the best answers. The ABC-based demonic registration approach still has several drawbacks despite its many benefits. Its settings need to be optimized to increase its ability to adapt to various image types and its scalability to massive image datasets. In conclusion, when employed in demon registration, the ABC algorithm has been shown to be a promising and effective technique for medical image registration. The current work did not use other image analysis tools or metrics, such as the structural similarity index (SSIM), mean square error (MSE), mean joint entropy (MJE), or image quality analysis (IQA), in the postprocessing of the framework. The current work did not use other image registration techniques or did not discuss deep learning methods or whether they can be applied to various image registration methods. The study is still pilot in nature, and future work may enhance the study by comparing the results of the current study with other optimization-based registration frameworks.

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