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Revolutionizing nonrigid demons registration with the whale optimization algorithm

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ABSTRACT

Image registration is one of the popular image transformation models in satellite and medical imaging currently. Image registration refers to image mapping with two or more than images. The ground-breaking fusion of the whale optimization algorithm and nonrigid demons registration (WOA-NDR) is applied in the current work to improve image registration's precision and effectiveness. NDR is an effective method for aligning images that have pliable structures. Nevertheless, it frequently runs into issues with local minima and massive deformations. To address these issues, WOA-which draws inspiration from whale hunting behavior-is integrated into the NDR architecture. The WOA-NDR approach intelligently explores the solution space, enhancing convergence and avoiding premature convergence. With the innovative WOA and NDR integration, the nonrigid image registration process is revolutionized and yields superior outcomes in terms of robustness and accuracy. The efficiency of the suggested strategy is demonstrated by experimental findings on a dataset of monomodal images. The obtained results are also compared with particle swarm optimization (PSO) based framework.

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1. INTRODUCTION

In computer vision and medical imaging, image registration optimization is an essential step. It entails aligning two or more images to provide precise data fusion, comparison, and analysis. By determining the best transformation [1] to project one image onto another, this alignment is accomplished. In many applications, such as object detection, image stitching, 3D reconstruction, and image-guided therapies, image registration is crucial. However, occlusions, geometric distortions, and image noise make exact and effective image registration difficult. Several optimization strategies have been developed to overcome these difficulties. By using these methods, the best transformation parameters that reduce the disparity between the registered images can be found. In medical imaging, image registration [2], [3] is essential for illness monitoring, diagnosis, and therapy planning. Accurate alignment of images taken from different angles or at different periods is made possible, as the integration of data from several imaging modality image registrations is utilized in computer vision for a number of purposes, including stereo vision, object tracking, image fusion, and image analysis. It improves image alignment speed and accuracy, which makes artificial intelligent (AI) models more resilient and broadly applicable. In computer vision and medical imaging, image registration optimization is a basic step. It makes it possible to align images for precise analysis and makes it easier to combine data from various sources. By reducing disparities among registered images, it improves the dependability, performance [4], and potency of different applications.

A complex method utilized in computer vision and medical imaging is called nonrigid demons registration. In particular, it takes into consideration deformable, nonlinear picture transformations. Nonrigid registration may handle more complicated transformations, such as stretching and bending, in contrast to standard ("rigid") registration methods, which support only translation and rotation. Therefore, it is especially helpful in fields such as biomedical imaging, where patient placement and organ motion can result in large deformations. The efficiency and accuracy of the "demons" method make it a popular option for nonrigid registration. It employs an iterative process to estimate the displacement field that is used to transfer one image onto another, "warping" the source image to match the target. Nonrigid device registration, despite its complexity, has been shown to be quite useful in enhancing the accuracy of image-based diagnosis and therapies.

Thirion suggested image matching [1] as a diffusion mechanism in 1998. Using an analogy with Maxwell's devils, he presented the idea of diffusing models to carry out image-to-image matching in this study. A demons algorithm for image registration with locally adaptive regularization was presented by Cahill *et al*. in 2009 [2]. In this study, they demonstrated how the linear complexity and implement ability of the original demons algorithm may be preserved while allowing for image-driven locally adaptive regularization. Demon registration was proposed by Thierry *et al.* in 2014 [3] for 3D images acquired via serial block face scanning electron microscopy. An experimental investigation of a symmetric version of Thirion's demon's method, which was used to realign 3D images acquired via serial block face scanning electron microscopy (SBFSEM), is presented in this paper. Papiez *et al.* in 2018 [5] presented a deformable image registration method for liver applications that uses supervoxels for local structure-preserving regularization. Supervoxel-based motion regularization was introduced in this research, offering integrated discontinuity preservation prior to motions such as sliding. More specifically, they used quick, structure-preserving guided filtering in place of Gaussian smoothing to produce effective, locally adaptive regularization of the estimated displacement field. The whale optimization algorithm was first presented by Mirjalili and Lewis in 2016 [4]. The whale optimization algorithm (WOA), a revolutionary nature-inspired metaheuristic optimization algorithm that emulates humpback whale social behavior, was proposed. A systematic review of WOA was provided by Nadimi-Shahraki *et al.* in 2023 [6]. The WOA was examined critically in this study. The advancements in WOA over the last five years were then thoroughly reviewed in this article. The current work uses WOA-based nonrigid demons registration and compares it with the particle swarm optimization [7] (PSO)-based framework. The rest of the paper is organized as follows: section 2 discusses the methodologies involved, the proposed method is discussed in section 3, the results are analyzed and discussed in section 4, and the paper concludes in section 5.

2. METHOD

The proposed framework uses two major techniques: nonrigid demonstration registration and the WOA. The proposed framework integrates two advanced techniques to enhance the image registration and optimization processes. Nonrigid demonstration registration is employed to accurately align images by accommodating complex deformations, allowing for a more precise mapping of anatomical structures. This method effectively handles variations in shape and size, making it particularly useful in medical imaging. Similarly, the WOA is utilized to enhance parameter tuning and search efficiency within the framework. Inspired by the social behavior of whales, the WOA optimizes solutions by simulating their hunting strategies, thus improving the overall performance and accuracy of the image registration process in dynamic contexts. They are discussed below:

2.1. Demons registration

Image registration [8] is a process in computer vision and image processing that aligns two or more images of the same scene taken at different times, from different viewpoints, or by different sensors. It is crucial for tasks such as object recognition, 3D reconstruction, and medical imaging. The term "demons" in image registration [1] specifically refers to a type of algorithm used for nonrigid image registration. Nonrigid registration is used when the transformation between images involves local deformations, such as in medical images where organs can slightly change shape between scans. The demons algorithm operates by iteratively deforming one image to match another. It estimates the displacement field (vector field indicating how pixels move from one image to the other) by minimizing an energy function that represents the difference between the images. This process is often implemented via gradient descent or similar optimization techniques. The overall goal of image registration [2], [3] is to find the transformation parameters that minimize the discrepancy between the images according to the chosen similarity metric. The specific choice of components (cost function, transformation space, and optimization strategy) depends on the characteristics of the images and the application requirements (such as speed, accuracy, and robustness to noise or artifacts). In medical image registration [4], [5], incorporating regularizers into the cost function helps to enforce smoothness or continuity in the transformation field. These regularizers play crucial roles in improving the accuracy and reliability of the registration process, especially when dealing with complex deformations or noisy data. While demons registration offers powerful capabilities for aligning biomedical images, incorporating constraints such as one-to-one mappings and diffeomorphism ensures that the transformations are biologically plausible and clinically meaningful. These developments are crucial for advancing the accuracy and reliability of medical image registration techniques in diagnostic and therapeutic applications. Nonrigid registration is crucial in medical imaging because of the deformable nature of soft tissues and the need for precise alignment in various clinical applications. This is why nonrigid registration is particularly suitable for medical images, along with some insights into its development and reviews in the fields of soft tissue deformation, tumor monitoring and others. Soft tissues in the human body can undergo significant deformations due to factors such as organ movement, physiological changes, or pathologies such as tumors. Nonrigid registration [9] allows these deformations to be captured accurately over time. In the demon’s algorithm for deformable image registration (DIR), the basic idea is that centroids in the static (reference) image exert local forces (or “demons”) that can adjust the gray level in the moving image to align with the static image. During each iteration of the original demonstration algorithm [6], a displacement vector $dr = (dx, dy, dz)$ is applied to each centroid in the moving image to progressively deform it toward better alignment with the static image

$$dr^{(n+1)} = \frac{(I_m^{(n)} - I_s^{(0)})\nabla I_s^{(0)}}{(I_m^{(n)} - I_s^{(0)})^2 + \left|I_s^{(0)}\right|^2} \tag{1}$$

2.2. Whale optimization algorithm

In 2016, Mirjalili and Lewis [4] created the whale optimization algorithm (WOA), an optimization method inspired by nature. It imitates humpback whale social behavior [7], especially the distinctive bubble-net feeding technique. This approach is used to resolve challenging optimization issues in a variety of domains and falls under the larger umbrella of swarm intelligence.

Bubble net feeding is a unique activity of humpback whales, in which they encircle a school of fish in spiral-shaped bubbles in an attempt to catch them. Three basic steps are involved in this behavior:

- Encircling prey: Whales encircle their prey by swimming in a decreasing circle;
- Bubble-net attack: They build a cylindrical net by blowing bubbles as they plunge down and swim upwards in a spiral pattern;
- Feeding: Whales swim through the net and eat trapped fish.

The WOA mimics the encircling, bubble-net attack, and feeding methods of humpback whales by using these behaviors to direct the search process in optimization problems. The three primary stages of the WOA algorithm are designed to simulate the hunting behavior of whales mathematically:

2.2.1. Encircling prey

Once they locate their meal, whales circle around them. The best potential solution is regarded as the prey or target in the optimization setting. Whale positions are updated in accordance with the location of the best solution thus far discovered. This behavior is represented as (2), (3):

$$\vec{D} = |\vec{C} \cdot \vec{X}*(t) - \vec{X}(t)| \tag{2}$$

$$\vec{X}(t+1) = \vec{X}*(t) - \vec{A} \cdot \vec{D} \tag{3}$$

where $\vec{X}*$ is the position vector of the best solution, $\vec{X}$ is the position vector of the current solution, t is the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors calculated as (4), (5):

$$\vec{A} = 2\vec{a} \cdot \vec{r} - \vec{a} \tag{4}$$

$$\vec{C} = 2 \cdot \vec{r} \tag{5}$$

Where $\vec{a}$ decreases linearly from 2 to 0 over the course of the iterations, and $\vec{r}$ is a random vector in [0,1].

2.2.2. Bubble-net attacking method

Two methods are used to achieve the bubble-net feeding strategy: a spiral updating position and a shrinking encircling mechanism.

– Shrinking encircling mechanism: This mechanism is accomplished by lowering $\vec{a}$, which shortens the range of $\vec{A}$ s and permits whales to approach prey more slowly.
– Spiral updating position: This technique simulates the way whales move in a helix as they get closer to their meal. The representation in mathematics is:

$$\vec{X}(t+1) = \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + X^{\rightarrow} * (t) \quad (6)$$

where $\vec{D}'$ is the distance between the whale and the prey, b is a constant defining the shape of the logarithmic spiral, and l is a random number in [-1, 1]. Using a probability p, a random selection is made between the spiral model and the shrinking encircling mechanism to update the whale's position.

2.2.3. Search for prey

The WOA additionally permits whales to search at random to improve exploration. This stage is especially helpful in broadening the scope of the search and preventing local optima. This behavior's mathematical model is as (7), (8):

$$D^{\rightarrow} = | C^{\rightarrow} \cdot X^{\rightarrow}_{rand} - X^{\rightarrow} | \quad (7)$$

$$\vec{X}(t+1) = X^{\rightarrow}_{rand} - \vec{A} . D^{\rightarrow} \quad (8)$$

where $X^{\rightarrow}_{rand}$ is a random position vector chosen from the current population.

In conclusion, the whale optimization algorithm is a strong and adaptable optimization tool that draws inspiration from humpback whale behavior in its natural state. This approach provides a novel approach for solving challenging optimization problems because of its distinctive method of mimicking the bubble-net feeding process. The versatility and ease of use of the WOA make it an important addition to the family of nature-inspired optimization algorithms, as it may be employed successfully in a variety of contexts.

3. PROPOSED METHOD

The monomodal images [10], [11] obtained from a tennis video [12] were initially sourced from the aforementioned database, as depicted in Figure 1. The selected images were sent to the framework. Demons registration was applied to the target image. The whale optimization algorithm optimized the parameters of the demonstration registration, where the window size of the Gaussian filter was optimized in the range of 20--100, while the sigma value varied from 0--20.

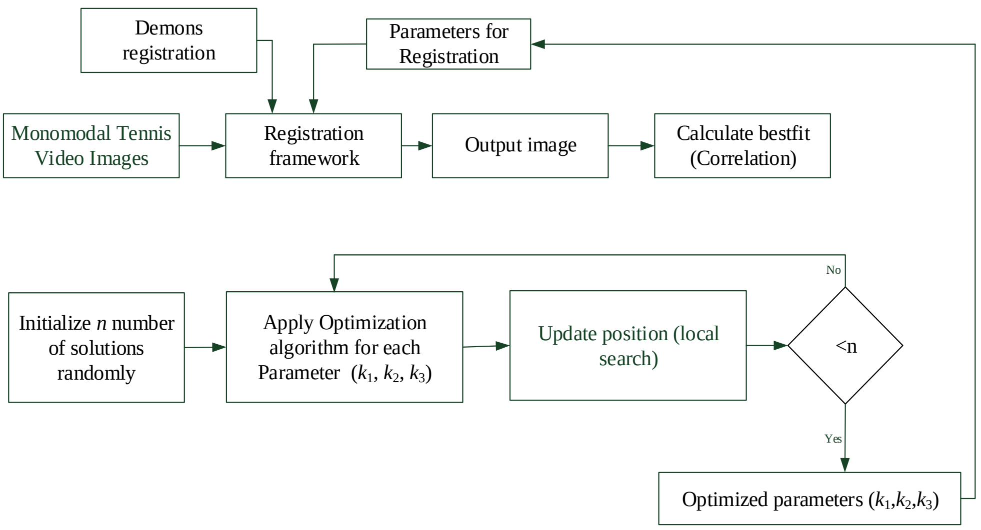


Figure 1. Block diagram of the proposed framework

In the current work, the whale optimization algorithm has been used, and it has been compared with the particle swarm optimization-based nonrigid registration [13], [14] framework. The proposed method involves the use of a registration framework for monomodal tennis video images. It starts with demons registration and parameter initialization, followed by an optimization algorithm applied to each parameter. The process iterates through local search updates, calculating the best fit via correlation until optimized parameters are achieved.

4. RESULTS AND DISCUSSION

A Ryzen 5 3.2 GHz processor and MATLAB R2018a were used to test and execute the current work's picture registration, particle swarm optimization, and whale optimization algorithms. The source of the monomodal dataset is [12]. The performance evaluation parameter was the correlation coefficient between the source image and the finished image. The population under both the WOA and PSO frameworks was fixed at 15. Table 1 lists the assessment metrics as well as the three parameters (k_1, k_2, and k_3) that need to be tuned for the demons registration framework based on the WOA.

Table 1. Whale optimization algorithm-based nonrigid demons registration

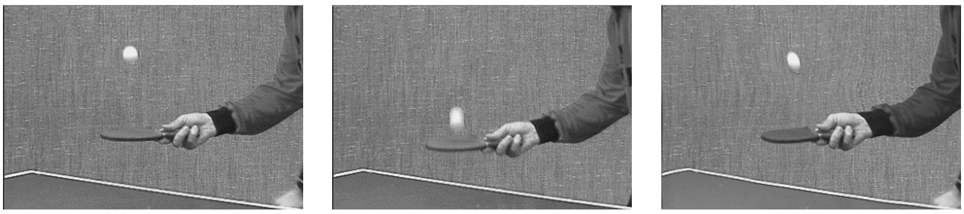
Iterations	k_1	k_2	k_3	Best fitness (correlation)	Processing time (seconds)
5	35	20	20	0.5986	119.93
10	62	99	20	0.6850	201.05
15	90	96	20	0.6928	322.21
20	99	99	20	0.6932	410.55
25	99	99	20	0.6932	488.73
30	99	99	20	0.6932	597.64

Table 2 shows that as a result of the particle swarm optimization [15], [16] algorithm-based nonrigid demons registration framework. The optimal value was obtained after the 25th generation at the best fitness value of 0.6925, which was the correlation between the reference and registered images. Establishing that the registration error was significantly low.

Table 2. Particle swarm optimization-based nonrigid demons registration

Iterations	k_1	k_2	k_3	Best fitness (correlation)	Processing time (seconds)
5	24	52	14	0.5819	323.17
10	46	71	16	0.6696	566.76
15	55	89	18	0.6891	871.61
20	81	92	19	0.6911	1094.23
25	98	98	19	0.6925	1432.91
30	98	98	19	0.6925	1781.39

Table 1 shows the obtained optimization values for nonrigid demonstration registration when the WOA is applied. The current framework is optimized after the 20th iteration and achieves even better correlation than the PSO-based [17], [18] framework, with a value of 0.6932. This means that the registration error [19], [20] between the registered image and the reference image is very low. The images obtained from the whale optimization-based nonrigid demonstration registration framework is shown below in Figure 2. The 3rd image in the image matrix clearly shows that the optimization framework has significantly improved the quality of the obtained image.



Reference Target Registered

Figure 2. Reference, target and optimized demons registered images

WOA-based nonrigid demons registration frameworks are faster than are PSO-based [8], [9] registration methods. The WOA-based rigid algorithm took the least amount of time to converge and obtain the optimal fitness in this comparative analysis. Overall, the optimization frameworks show that the WOA-based rigid registration [21], [22] framework was relatively faster than the PSO-based framework, but in terms of image quality, the WOA [17]-based nonrigid registration managed to achieve the least registration error.

The WOA has demonstrated benefits such as ease of use, quick convergence, and a sensible ratio of exploration to exploitation. It features an easy-to-use interface and has been developed in other computer languages. Figure 3 shows that the whale optimization-based demons registration framework achieves a higher fitness value than does the particle swarm optimization-based framework.

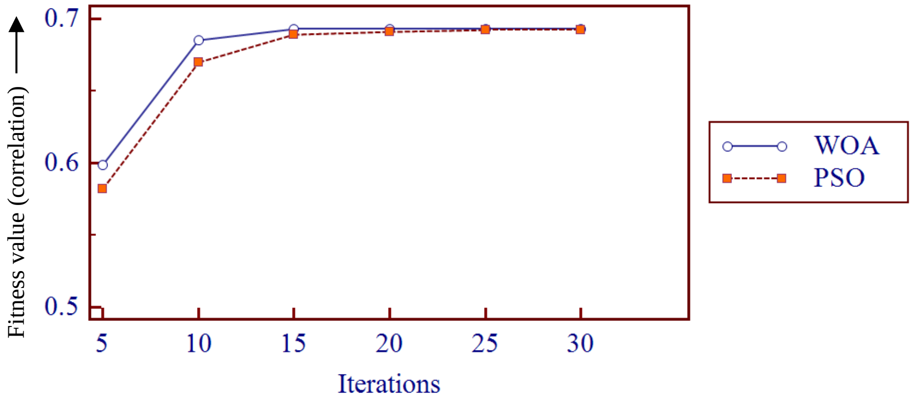


Figure 3. Comparative analysis of the optimal fitness of different frameworks

Figure 4 shows that the whale optimization algorithm-based nonrigid demons registration [23], [24] framework was significantly faster than the particle swarm optimization-based framework. The current work aimed at reducing the time complexity, and the WOA-based [25], [26] framework managed to achieve that goal. As reported earlier in Tables 1 and 2, the convergence was also faster in WOA-based [27] nonrigid registration.

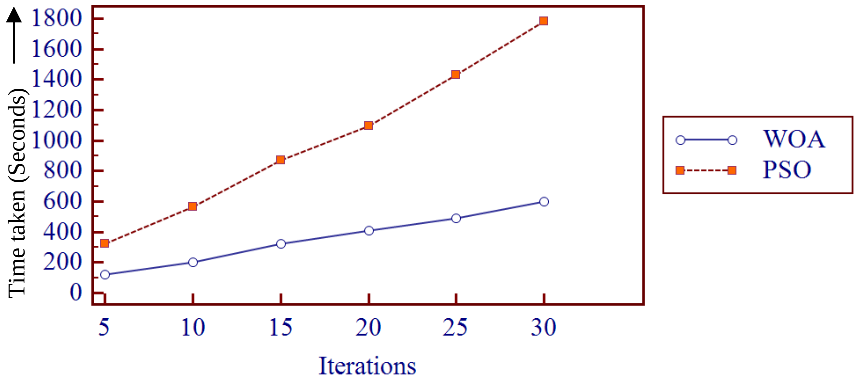


Figure 4. Time complexity analysis

The WOA method is an effective tool for optimizing work in a variety of industries because it has demonstrated high accuracy and efficiency. Two evolutionary optimization techniques [28] have been employed for picture registration tasks: the WOA [18] and PSO [14]. Compared with traditional optimization techniques, the WOA and PSO have both been employed successfully to handle image registration challenges, resulting in faster convergence and alignment precision. However, the nature of the photographs and the optimization parameters used can influence how effectively these algorithms perform. Overall, the data in Tables 1-2 and Figures 3-4 clearly reveal that the WOA-based demons registration framework outperforms the PSO-based framework in terms of speed and accuracy.

5. CONCLUSION

A promising development in computer vision and medical imaging is whale optimization-based nonrigid demons registration. By utilizing the intelligence of whale optimization, this method efficiently manages image registration defects, resulting in increased accuracy and efficiency. Its application in biomedical imaging has proven invaluable, improving the accuracy of diagnostic processes and treatments, despite some computational challenges. Improvements in this technique will surely lead to even greater speed and precision as research continues, enhancing the potential of medical imaging and highlighting the significance of nonrigid demonic registration in the AI and healthcare industries. The current work aimed to improve the existing demon's registration framework. From the above discussion, along with Tables 2 and 3 and Figure 3, it is quite clear that the framework managed to enhance the demon's registration framework. Figure 4 also shows that the time complexity was reduced as a result of the WOA-based demons registration framework. Future work may include the use of other optimization algorithms and comparisons with the proposed system.

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