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Bio-Inspired Fossil Image Segmentation for Paleontology

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***Abstract*— Dinosaurs are part of our history and investigating about them could provide a vivid picture of our planet in more than a million years ago. However, most of them are extinct but, investigation is possible to be conducted on their remains or fossils. Hopefully, plenty of dinosaur's fossils are preserved by nature and their images are collected by scientist and made available. Image segmentation applications in this subject is a proper tool for paleontologist. They can use this tool for counting number of bones in a sample and getting some geometrical details about each part. This paper presents, the application of employing multiple bio-inspired or Metaheuristic image processing techniques on some dinosaurs' fossils images. In order to adjusting the contrast, Evolution Strategy histogram equalization is employed. Also, Cultural Algorithm image quantization is used for quantitating the input image. Simulated Annealing edge detection algorithm, separates each part, precisely. Main step is hybrid Particle Swarm Optimization / Simulated Annealing segmentation, which provides final segmented image for investigation. Final acquired results, illustrates more details and rather clear segmented images in comparison with traditional segmentation methods.**

Keywords—Dinosaur' Fossil, Bio-Inspired Algorithms, Cultural Algorithm Image Quantization, Evolution Strategy Histogram Equalization, Simulated Annealing Edge Detection, Particle Swarm Optimization Image Segmentation

I. INTRODUCTION

Gathering information about earth's past events is vital for getting better understanding of how some species extinct, in order find solutions and prevent it from happening again. Our earth is aged for millions of years and provided life for lots of species, including dinosaurs. Some of these dinosaurs are still alive, like bird [8] but, most of them are extinct due to climate change, natural disasters and asteroid impact [9]. Investigating history is always fascinating for mankind, as it is possible to understand how our ancestors and other creatures lived, survived and died during times. Nature is preserved some evidence of this history by their remaining fossils. Here, dinosaurs' fossils are investigating by image processing [10] techniques. It seems bio-inspired or metaheuristic algorithms [11] could cope with different image processing tasks which it is the main reason they are using as main tools in this paper. These metaheuristic image processing techniques could easily overperform tradition methods which makes them more desirable to employ. For our method some metaheuristic image processing and main techniques are used to gain the final segmented image. Paleontologists [8] could use proposed method in order to getting better analysis on dinosaur's fossil. This paper is consisted of five main sections. Section I related to some basic definitions. Image segmentation is a base method for object detection and recognition and has application in industry, health care, security, agriculture, space researches, paleontology and more [5]. Section II concerns some of the related researched on the subject. Section III pays to proposed bio-inspired image segmentation method in details. Section IV presents experiment results and comparison with traditional methods. Section V includes, conclusion, future work and recommendation for final reader.

II. PRIOR RELATED RESEARCHES

Clearly K-means [1] algorithm could cluster close groups of samples into different number of clusters based on their distance in the space. Same method could be employed for image pixel values which, could be gray level, intensity or color. One of the best implementations for K-means on images belongs to Dhanachandra, N, et al in 2015 [2]. Obviously, this method is categorized into cluster-based segmentations methods. Another example is Watershed image segmentation algorithm [3]. It is a region-based method and this algorithm is based on drainage in basins or rivers. It works based on the water level as water height represents the separating line between one region or segment to another. A commonly used segmentation technique is called Otsu's thresholding segmentation [4] which is categorized in threshold-based segmentations. It works as a thresholding process for pixel intensity values in order to minimizing interclass variance for separating pixels into two classes of foreground and background. Number of threshold value, determines, number of segments. Another mentionable method for segmentation is using Gabor filters [6] as a region-based technique. In this method which sometimes calls image texture segmentation, system tries to differentiate between objects' patterns by their shape. Also, using bio-inspired algorithms in order to segmenting digital images is so popular. One of these examples is employing K-means clustering and Genetic algorithm for image segmentation [7].

One of the fascinating types of research in digital restorations of fossil images by various image processing techniques including image pre-processing, morphological operations [13] and segmentations in3-dimentional environment belongs to Lautenschlager, Stephan which is conducted in 2016 [12]. Another valuable research for paleontological material segmentation conducted by Dunmore, Christopher, et al in 2018 [14]. They used K-means and Fuzzy C-means clustering to achieve their goal. Hou, Yemao, et al succeeded to make a system which reconstructs

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3-D model of fish microfossils using deep learning from CT data in 2021 [15]. One of the greatest research projects in this area belongs to Yu, Congyu, et al in 2022 [16]. They made a CT database of dinosaur's fossils from Gobi Desert, Mongolia. They used U-Net; a deep neural network segmentation technique to perform their experiment. All of mentioned researches have some advantages and drawbacks which, in this paper an effort to overcome these drawbacks is made. Drawbacks are weak result in images with different intensity, being exclusive to just black and white or gray images, high run time speed for big image data, algorithm confusion in a busy and complex images and misclassification.

III. Proposed Bio-Inspired Segmentation Method

Proposed image segmentation method is consisted of four bio-inspired image processing techniques. System starts with getting image data from input and sends it to the histogram equalization [17, 18] step which is conducted by Evolution Strategy (ES) algorithm [19]. Here, target histogram fits by evolution strategy algorithm to adjust the intensity of the input image. Next step reduces image size by quantitating image [20] into specific number of threshold levels. This step is vital to have better edges in the next step. This part performs by Cultural Algorithm (CA) [21, 22] by fitting threshold levels vector. Quantized image sends to edge detection [23, 24] step which is conducted by Simulated Annealing (SA) algorithm [25, 26]. Here, SA selects best filters for image by its evolutionary feature selection approach and applies it on image. After revealing edges, it is time to segment the image. For image segmentation part, Particle Swarm Optimization (PSO) [27, 28] algorithm with the aid of SA algorithm as its optimizer is considered [29]. Finally, all evolutionary steps overlays for having more detailed segmented image. Fig 1 represents the process of proposed method. Fig 2 shows an example of proposed method on a real image data. Table I presents proposed method as a pseudo code.

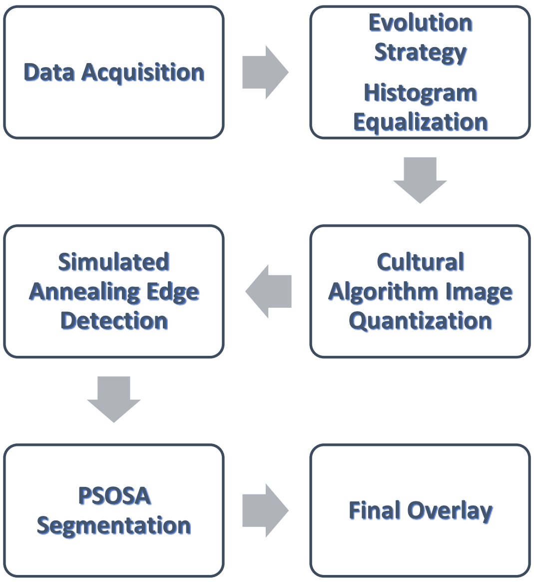

Fig. 1. Proposed method process.

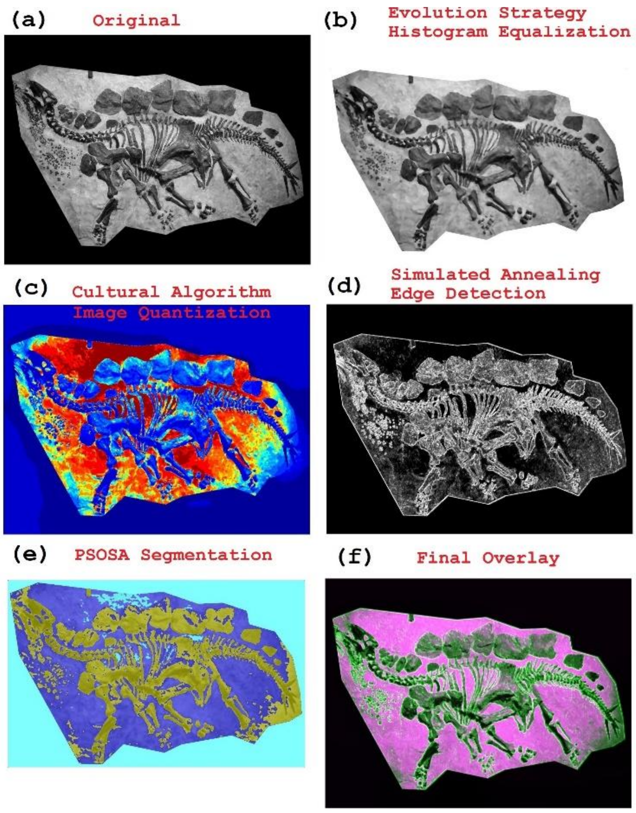

Fig. 2. Proposed segmentation method on a real image data – Image from Explore Houston Museum of Natural Science (Stegosaurus).

IV. Validation and Experiment Results

In order to evaluate the performance of the proposed segmentation method, three most famous performance metrics of accuracy [30], boundary F1 score [31] and Intersection over Union (IoU) [32] metrics are employed which, has application in comparison step too. Accuracy simply is the ratio of correctly classified pixels for objects. Fig 3 shows the image samples used for the experiment. Table II represents all parameters which are used for all four bio-inspired image processing algorithms.

Accuracy Score = Number of True Positive / (Number of *True Positive + Number of False Negative)* *(1)*

The boundary F1 (BF) contour matching score indicates how well the predicted boundary of each class aligns with the true boundary. The BF score is defined as the harmonic mean (F1-measure) of the precision and recall values with a distance error tolerance.

*F score = 2 * precision * recall / (recall + precision)* *(2)*

Intersection over union (IoU), also known as the Jaccard similarity coefficient, is the most commonly used metric for segmentation. IoU is a statistical accuracy measurement that penalizes false positives. For each class, IoU is the ratio of correctly classified pixels to the total number of ground truth and predicted pixels in that class

IoU score = True Positive / (True Positive + False Positive + False Negative) *(3)*

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TABLE I. PSEUDO CODE FOR PROPOSED METHOD

```
Start
  Loading Image
  Training Using Evolution Strategy Algorithm (Input: Raw Image and Target Histogram Vector)
  Goal: To Adjusting the Intensity by Equalizing the Image Histogram
      Initialize the Population Size N and Number of Generations
      While (number of generations is not reached)
              Recombination of Attributes and Variances of Individuals
              Mutation of Attributes and Variances
              Evaluation of Fitness Function for Individuals
              Selection for New and Best Individuals (Best Target Histogram Value)
      End While
              Apply Best Selected Target Histogram Vector
    End of ES
    Output: Evolutionary Intensity Adjusted of Target Histogram for Raw Input Image
    Training Using Cultural Algorithm (Input: ES Equalized Histogram Image and Threshold Levels Vector)
    Goal: To Quantize the Image by Fitting Threshold Level
        Initialize the Population Size N and Number of Generations
        While (number of generations is not reached)
              Fitness Evaluation
              Updating Belief Space
              Reproduction Operators
              Influence and Acceptance Functions
              Selecting Best Individuals (Best Threshold Value)
        End While
              Apply Best Selected Threshold Level Vector
    End of CA
    Output: Evolutionary Fitted Threshold Level for Input Image
    Training Using Simulated Annealing Algorithm (Input: Quantized Image and Filter Matrix)
    Goal: To Select Best Edge Filters
        Initialize the Population Size N and Number of Generations
        While (number of generations is not reached)
              Objective Function Evaluation
              If  Objective Function Decreases
                      Update the Best Solution for Each Filter Vector
                      Reduce the Current Temperature
                      Generate a New Trial Solution and Go to Evaluation Step
              Else If Metropolis Criterion Is Meet
                      Go to Update Step
              Else
                      Go to Reduce Temperature Step
          End While
              Apply Best Selected Edge Filter
    End of SA
    Output: Evolutionary Edge Detected Image
    Training Using Particle Swarm Optimization + SA (Input: Edge Detected Input Image)
    Goal: To Segment the Input Image
        Initialize the Population Size N and Number of Generations
        While (number of generations is not reached)
              Initialized Particles with Random Position and Velocity for PSO
              Evaluate the Fitness of Particles for each Pixel and Their Corresponding Distance for PSO
              Objective Function Evaluation for SA as Optimizer
              Find and update pbest and gbest for PSO
              Reduce The Current Temperature for SA
              Calculate and Update Velocity and Position for PSO
              Generate a New Trial Solution and Go to Evaluation Step for SA
              Show gbest the Optimal Solution for PSO
              Desirable Temperature Reached for SA
              Update the Best Solution Found for Pixel and Distance by PSO+SA
          End While
              Apply Best Clusters Found on Image to Segment
    End of PSOSA
    Overlay All Evolutionary Techniques
    Output: Evolutionary Segmented Image
End
```

Also, four dinosaurs' fossils images belong to different paleontology period are used as test materials. Additionally, proposed method is compared with K-means [2], Watershed [3], Otsu's [4] and bio-inspired Genetic segmentation [7] algorithms on same test images and evaluated by mentioned three performance metrics by same parameters. Figs 4, 5, 6 and 7 represent ES histogram equalization, CA image quantization, SA edge detection and PSOSA image segmentation techniques on Dilophosaurus sample, respectively.

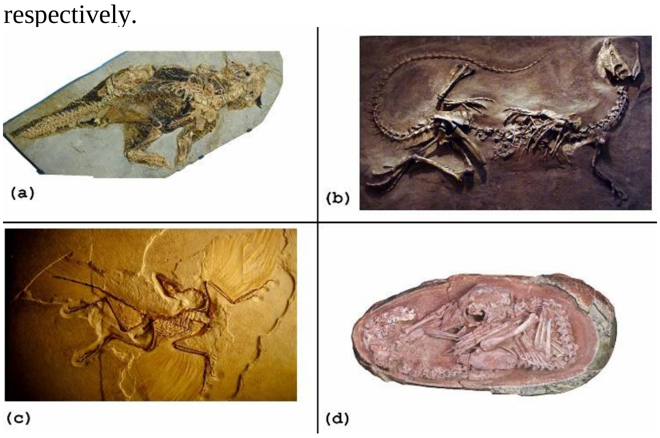

Fig. 3. Samples for the main experiment. (a) Psittacosaurus [33], (b) Dilophosaurus [34], (c) Archaeopteryx [35], (d) Preserved dinosaur Embryo [36].

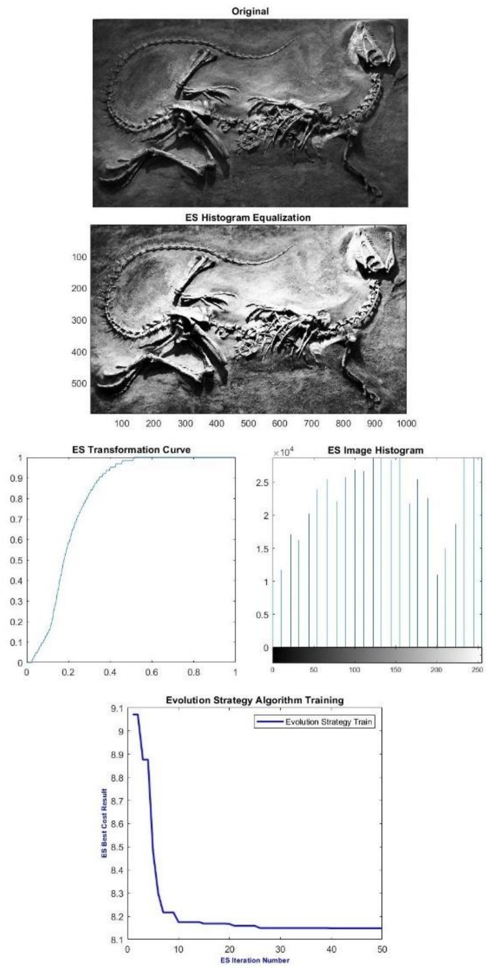

Fig. 4. Evolution Strategy histogram equalization on "Dilophosaurus" sample image.

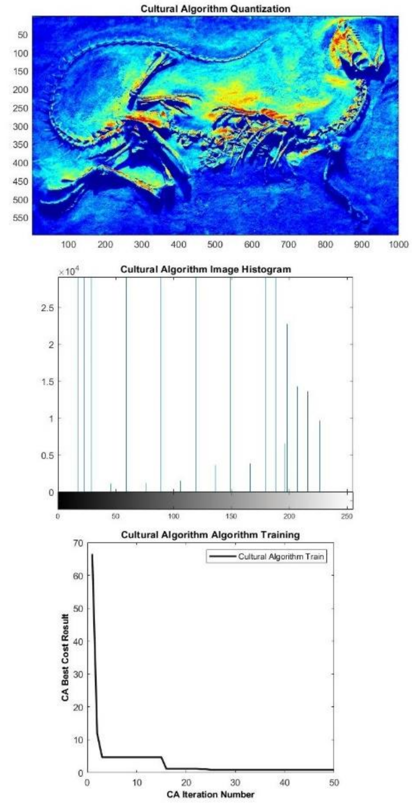

Fig. 5. Cultural Algorithm image quantization on "Dilophosaurus" sample image.

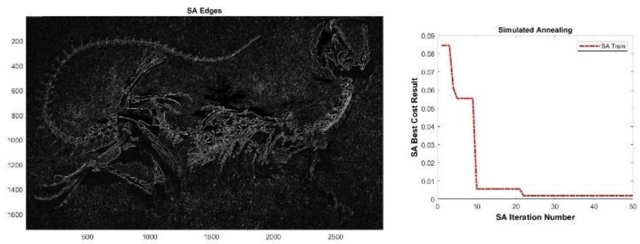

Fig. 6. Simulated Annealing edge detection on "Dilophosaurus" sample image.

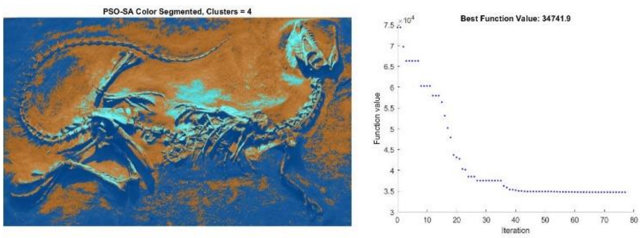

Fig. 7. PSOSA image segmentation on "Dilophosaurus" sample image.

Fig 8 shows all steps of proposed segmentation on Embryo sample. Also, Fig 9 shows the comparison result for all five methods on Archaeopteryx sample image. Table III present result of three segmentation performance metrics on four sample images and comparison with other methods. Clearly, proposed PSOSA segmentation and Otsu's methods achieved highest score and watershed method achieved lowest; it has to be mentioned that K-means and GA segmentations placed in the middle of this ranking. In Table III, closest value to 1, the better segmentation result. Fig 10 illustrates Table III as a Box plot.

TABLE II. METAHEURISTIC ALGORITHMS PARAMETERS

	Evolution Strategy Histogram Equalization	**Cultural Algorithm Image Quantization**	**Simulated Annealing Edges**	**Particle Swarm Optimization + SA Segmentation**
Iterations	50	50	50	100 for both
Sub Iterations	-	-	20	20 for SA
Number of Variables	10	10	-	Clusters, Clusters for PSO
Alpha	1	0.3	-	-
Population	(4+round(3*log(nVar)))*10	50	-	250 for PSO
Variable Min	-(10^alpha)	-(10^alpha)	-	Zeros of (Clusters * Clusters) for PSO
Variable Max	10^alpha	10^alpha	-	Ones of (Clusters * Clusters) for PSO
Parents = Mu	round(lambda/2)	-	-	-
Parent Weights = w	log(mu+0.5)-log(mu)	-	-	-
Effective Solutions = mu_eff	1/sum(w.^2)	-	-	-
Step Size = Sigma	0.3*(VarMax-VarMin)	-	-	-
Covariance Update = Alpha_mu	2	-	-	-
Acceptance Ratio = pAccept	-	0.4	-	-
Beta	-	0.5	-	-
Accepted Individuals = nAccept	-	pAccept* Population	-	-
Initial Temperature = T0	-	-	5	5 for SA
Temperate Reduce Rate = Alpha	-	-	0.99	0.99 for SA
Clusters	-	-	-	n
Variable Size	-	-	-	[Clusters, Clusters]
Swarm Size	-	-	-	250
Optimizer	-		-	Simulated Annealing
Inertia Coefficient = w		-	-	1
Damping Ratio of w = wdamp		-	-	0.99
Personal Acceleration Coefficient = c1	-	-	-	2
Social Acceleration Coefficient = c2	-	-	-	2

TABLE III. PERFORMANCE METRICS RESULTS ON ALL FOUR SAMPLE IMAGES AND COMPARISON WITH OTHER METHODS

	Otsu	**Watershed**	**K-Means**	**GA**	**PSOSA**
Accuracy (Psittacosaurus)	0.830	0.628	0.702	0.620	0.850
Accuracy (Dilophosaurus)	0.825	0.699	0.770	0.598	0.827
Accuracy (Archaeopteryx)	0.792	0.584	0.754	0.697	0.870
Accuracy (Embryo)	0.789	0.610	0.788	0.663	0.889
F-Score (Psittacosaurus)	0.719	0.586	0.600	0.635	0.884
F-Score (Dilophosaurus)	0.811	0.580	0.683	0.691	0.801
F-Score (Archaeopteryx)	0.746	0.597	0.650	0.699	0.857
F-Score (Embryo)	0.825	0.546	0.719	0.740	0.936
IoU or Jaccard (Psittacosaurus)	0.882	0.477	0.639	0.511	0.912
IoU or Jaccard (Dilophosaurus)	0.863	0.493	0.608	0.597	0.904
IoU or Jaccard (Archaeopteryx)	0.819	0.517	0.688	0.580	0.895
IoU or Jaccard (Embryo)	0.800	0.580	0.746	0.639	0.887

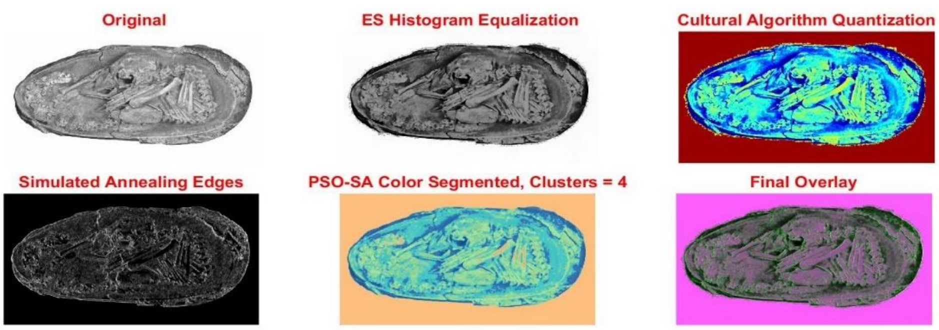

Fig. 8. Proposed segmentation on “Embryo” image.

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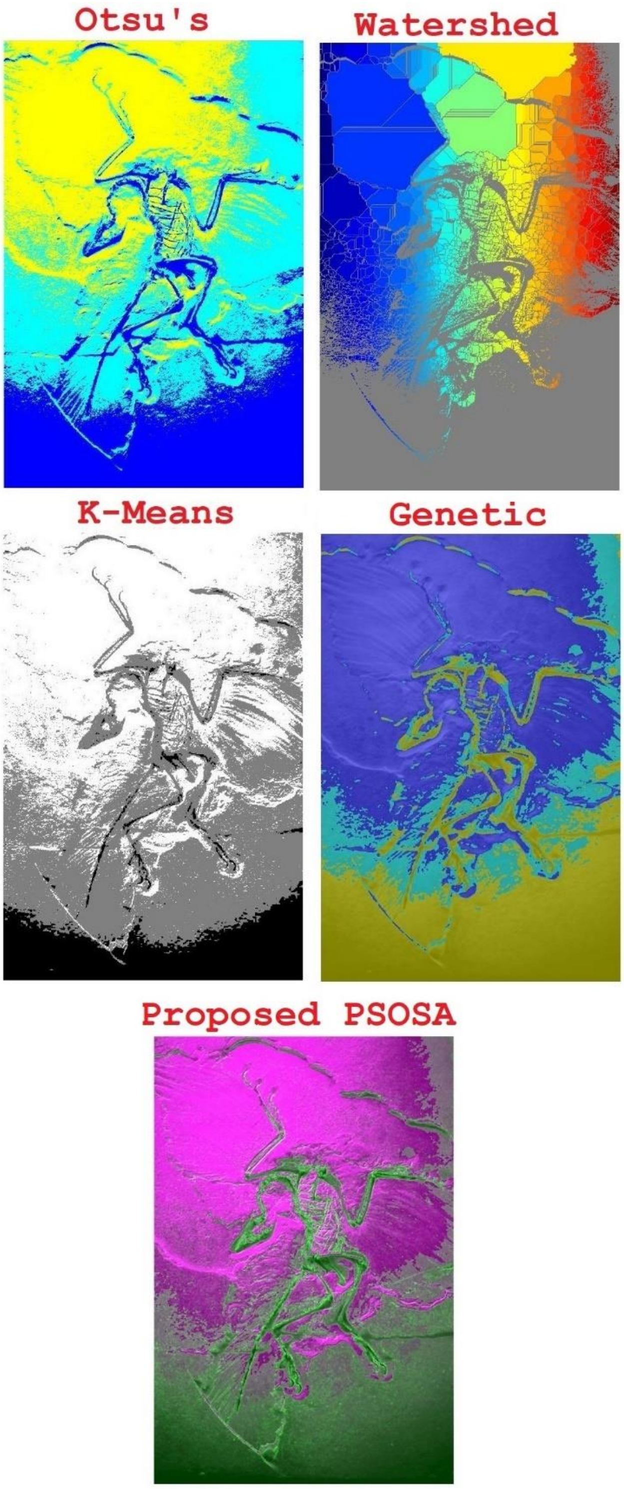

Fig. 9. Comparison of different segmentation methods on "Archaeopteryx" image.

V. CONCLUSION, FUTURE WORKS AND SUGGESTIONS

Empowered by multiple bio-inspired image processing algorithms to get final segmented image, proposed method could cope with different fossil image scenarios. The only problem here is computation time versus other methods, but ends up with a precise segmented image for paleontology researches. Overall, by playing of algorithm's parameters, it is possible to get faster run or if the model is already available, then it could be used in real time. However, traditional segmentation techniques could provide desirable result for most of the researches but, pushing some limits is always rational for precise researchers. Using this system for areas other than paleontology is of future works. Additionally, it is suggested to use other bio-inspired algorithms or even combined them to achieve different or even better results.

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