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3D Microscopy Vision Using Multiple View Geometry and Differential Evolutionary Approaches

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Outline

- Generic 3D Surface Reconstruction
- Microscopic 3D Surface Reconstruction
- Method
- Experimental Validations
- Conclusion and Future Work

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Generic 3D Surface Reconstruction

3D surface reconstruction refers to the process of creating 3D model from a set of 2D images.

Input: a set of 2D images

Output: 3D model

Fig 1. Generic 3D surface reconstruction. This work was done by Computer Vision Laboratory at Stanford University in 2013. 11,230 images were captured and camera traversed over 184 meters. (http://vision.stanford.edu)

Microscopic 3D Surface Reconstruction

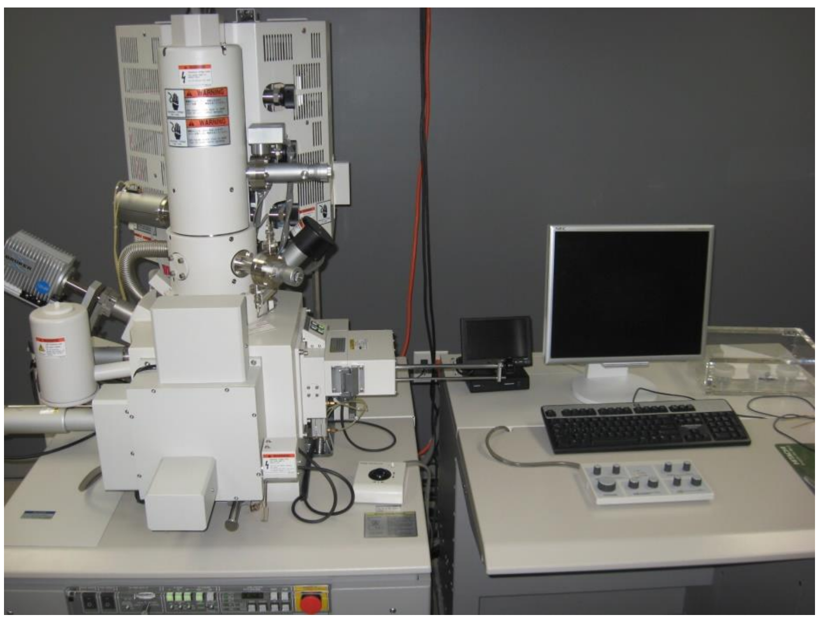
Motivations and Objectives

- To effectively measure and visualize the surface properties of 2D images taken by a Scanning Electron Microscope.
- To provide quantitative and visual information for microscopic samples.
- To create realistic anatomic shape from microscopic samples.
- To allow rotation and depth for further interpretation of microscopic objects.

Method

The Scanning Electron Microscope (Contd.)

- A SEM offers an excellent capability to overcome the limitation of the human eye by its ability to image microscopic surfaces and achieve increased magnification, contrast and resolution greater than 1 nanometer.



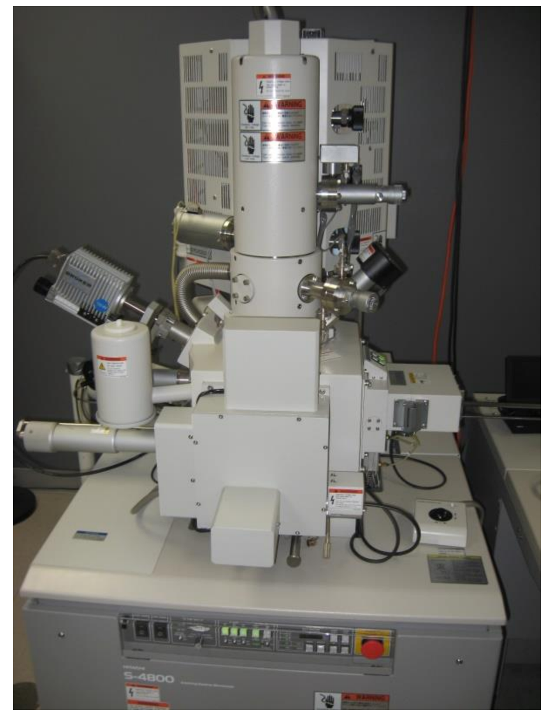


Fig 2. SEM is a type of electron microscope that produces images with a focused beam of electrons. Image courtesy of the EM Laboratory at University of Wisconsin Milwaukee (http://uwm.edu)

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Method

The Scanning Electron Microscope (SEM)

Table 1. Comparison of the SE and BSE imaging in a SEM

SE-based imaging	BSE-based imaging
Higher resolution and darker intensities	Lower resolution and brighter intensities
Inelastic scattering (low energy electrons)	Elastic scattering (high energy electrons)
Contains topographical information	Contains compositional information

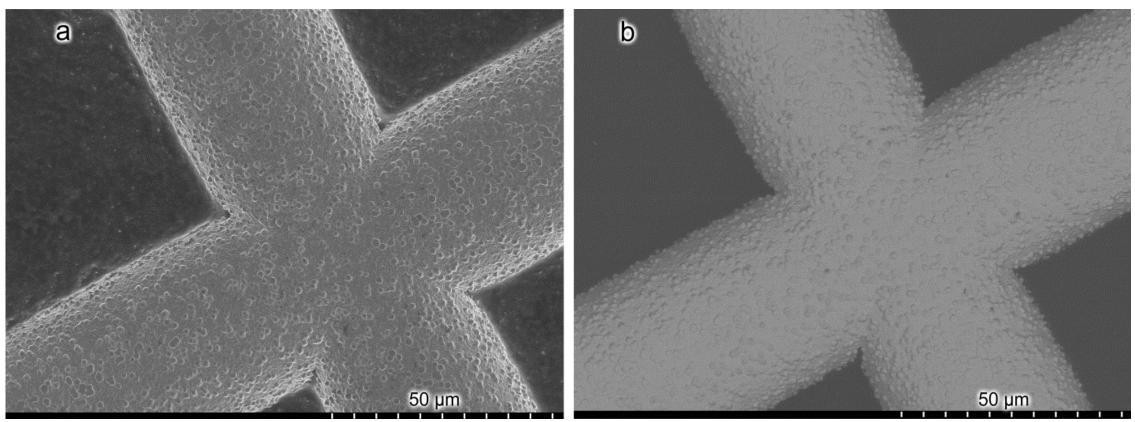

Fig 3. Secondary electron (SE) and Backscatter (BSE) micrographs of a *copper TEM grid*. SE micrograph **(a)** exhibits greater resolution and topography on the surface of the grid as well as in background. BSE micrograph **(b)** exhibits greater contrast and brightness between materials comprising the sample. Resolution compared to SE micrograph is much reduced. Image courtesy of the EM Laboratory at University of Wisconsin Milwaukee. (http://uwm.edu)

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Method

3D SEM Surface Reconstruction System (Contd.)

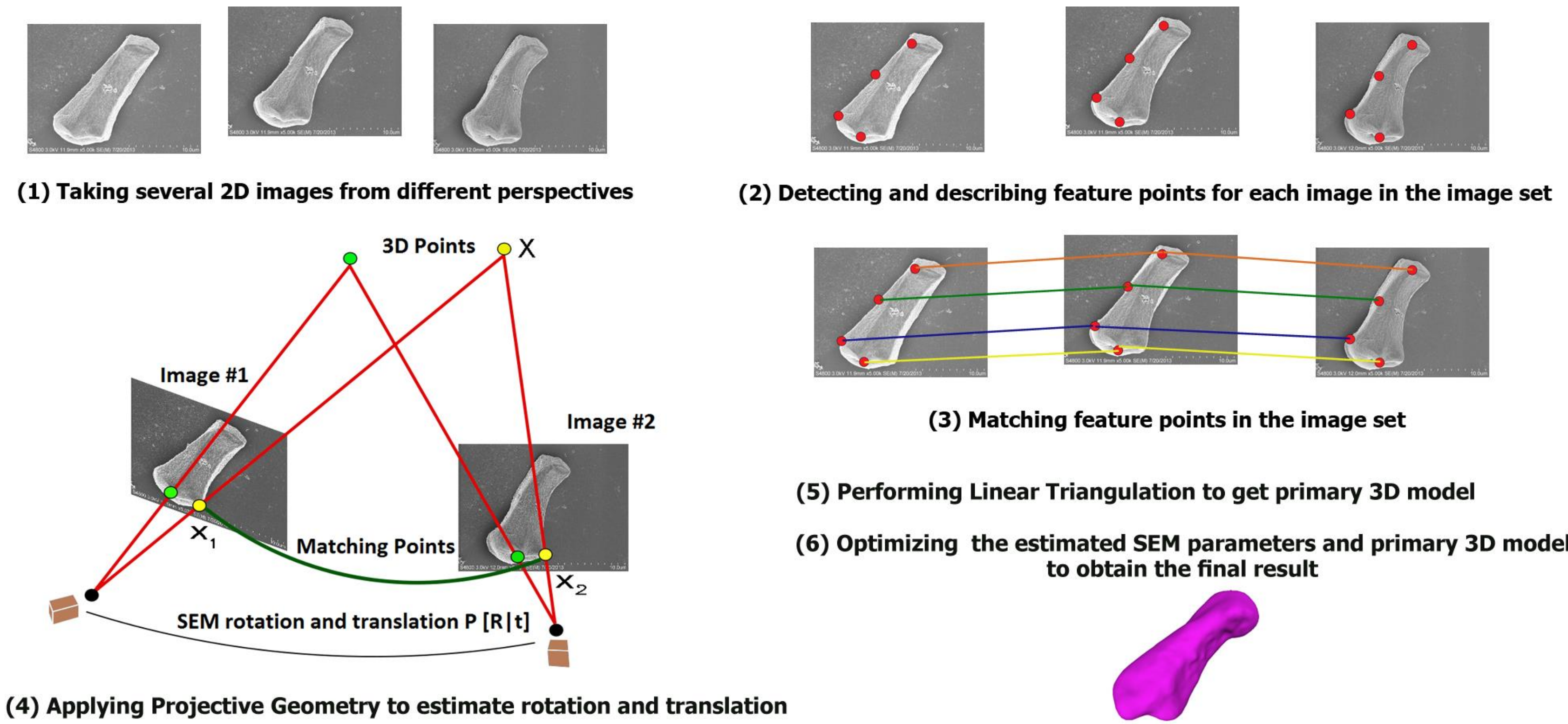


Fig 4. The proposed system for 3D SEM surface reconstruction. We use Projective Geometry (Multiple View Geometry) to initialize a 3D model, then perform Differential Evolutionary (DE) algorithm to refine both SEM parameters and 3D shape model.

Method

3D SEM Surface Reconstruction System (Contd.)

- Using the general pipeline of multi view 3D reconstruction, we normally initialize the 3D points and extrinsic parameters with some error thresholds.

- Suppose that we are given two 2D images with $\mathbf{N}$ matching points, then the aim is to estimate six parameters for modeling the camera motion ($\mathbf{R}$ and $\mathbf{t}$ known as extrinsic parameters) and $\mathbf{N}*3$ for the 3D points $\mathbf{X_i}$ by minimizing the following projection error:

$$E(X_1, ..., X_N, R, T) = \sum_{i=1}^{N} \|x_1^i - P(X_i)\|^2 + \|x_2^i - P([R \mid t], X_i)\|^2$$

- Parameterizing the space of **rotation** and **translation** is the most important portion of the problem.

- In order to have better flexibility, the quaternion parameterization is applied to 3D rotation representation.

Method

3D SEM Surface Reconstruction System (Contd.)

- A quaternion **z** = a + bi + cj + dk, where a, b, c, d are real numbers and $i^2 = j^2 = k^2 = -1$, and **z** is a unit quaternion if and only if:

$$|z| = \sqrt{a^2 + b^2 + c^2 + d^2} = 1$$

- Then the rotation matrix representation is as follow:

$$R(z) = \begin{bmatrix} a^2+b^2-c^2-d^2 & 2bc-2ad & 2bd+2ac \\ 2bc+2ad & a^2-b^2+c^2-d^2 & 2cd-2ab \\ 2bd-2ac & 2cd+2ab & a^2-b^2-c^2+d^2 \end{bmatrix}$$

- We denote the translation vector of the second position with respect to the first position as $\mathbf{t} = (t_x; t_y; t_z)^T$

Method

3D SEM Surface Reconstruction System (Contd.)

- By considering the previous equations for rotation parameterization and **t** for translation, then the parameterization of two projection matrices will be determined by a seven dimensional vector as follow:

$$\psi = (a, b, c, d, t_x, t_y, t_z)^\top$$

- The final optimization is:

$$\psi^* = \arg\min_{\psi}\left(\sum_{i=1}^{N} \|x_1^i - P(X_i)\|^2 + \|x_2^i - P(\psi, X_i)\|^2\right)$$

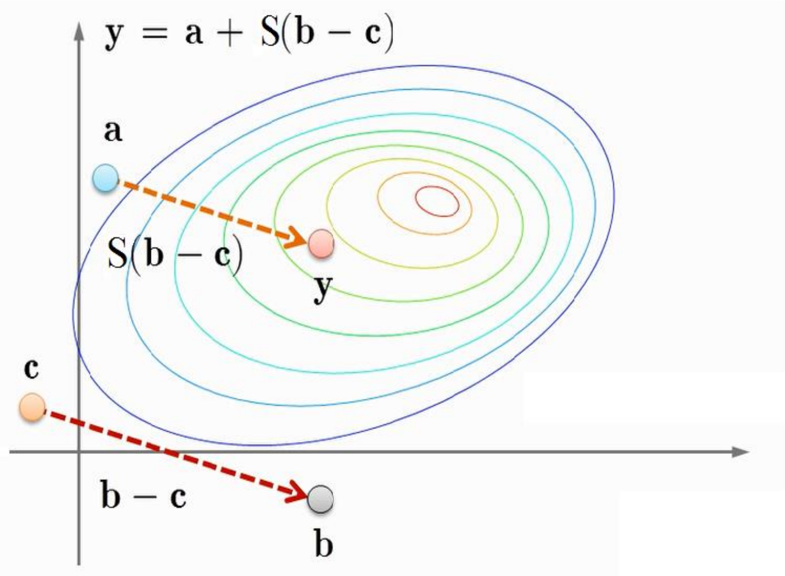
- We use Differential Evolution to solve the above equation.

Method

3D SEM Surface Reconstruction System

- DE is a minimization strategy using generated populations within the parameter space. This method first generates an initial population randomly, then iteratively updates them to estimate the best possible values for an optimization problem.

```
begin
 Initialize S, CR, P_Total, G_max;
 Initialize the population {ψ_i;(1<=i<=P_Total)} randomly;
 G = 1;
 while G < G_max
   for (i=1; i<= P_Total; i++)
      choose three individual agents ψ_{m,G}, ψ_{n,G}, ψ_{p,G} randomly;
        r = U(0,1);
        if r < CR
         m_{i,G} = ψ_{m,G} + S × (ψ_{n,G} − ψ_{p,G})
       else
         m_{i,G} = ψ_{i,G};
       if  m_{i,G} < ψ_{i,G};
        ψ* = m_{i,G};
     end.
   G = G+1;
 end.
return  ψ*
end.
```



The parameters $\mathbf{CR} \in [0; 1]$ and $\mathbf{S} \in [0; 2]$ will be obtained by performing several experiments on the problem.

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Experimental Validations

3D Visualization

Sample #1

Data (Sample)	Tapetal
# 2D Images	4
Tilting	9 Degree between each
# 3D points	1129
Resource	EM Laboratory, Biological Science Department, UWM

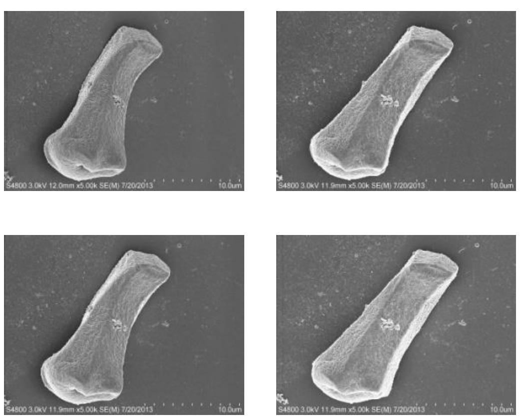


Fig 5. We took multiple 2D images from a *Tapetal cell* using Scanning Electron Microscope (SEM).

Going from 2D to 3D

Fig 6. We generated a 3D model of a *Tapetal* cell using only its 2D images. We solved inverse problem going from 2D to 3D.

Experimental Validations

3D Visualization

Sample #2

Data (Sample)	Diatom
# 2D Images	3
Tilting	15 Degree between each
# 3D points	531
Resource	EM Laboratory, Biological Science Department, UWM

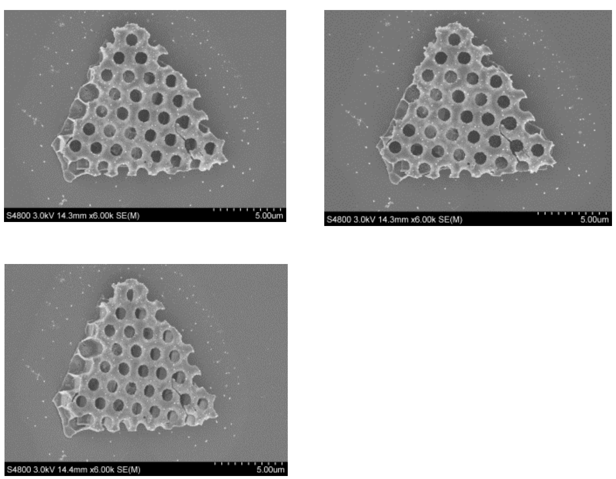


Fig 7. We took multiple 2D images from a *Diatom Frustule* using Scanning Electron Microscope (SEM).

Going from 2D to 3D

Fig 8. We generated a 3D model of a *Diatom* Frustule using only its 2D images. We solved inverse problem going from 2D to 3D.

Experimental Validations

SEM Extrinsic calibration

Table 2. Accuracy and reliability validation of the proposed method by examining different variables. ΔR is given as $R_{real} - R_{estimated}$, indicating error for estimating the 3D rotation. Rotation angles show the ground truth 3D SEM rotations(R_{real}). In each row we used only two images in the set.

Image set	Total Matches	Rotation angle	G_{max}	ΔR	Elapsed time
tapetal cell	509	9 degrees	500	2.12E-03	6.61 Sec.
tapetal cell	509	9 degrees	1000	5.07E-04	9.18 Sec.
tapetal cell	441	18 degrees	500	2.57E-03	6.53 Sec.
tapetal cell	441	18 degrees	1000	7.12E-04	8.89 Sec.
diatom frustule	317	15 degrees	500	2.88E-03	6.02 Sec.
diatom frustule	317	15 degrees	1000	7.13E-04	7.25 Sec.
diatom frustule	286	30 degrees	500	2.95E-03	5.81 Sec.
diatom frustule	286	30 degrees	1000	7.41E-04	4.97 Sec.

Experimental Validations

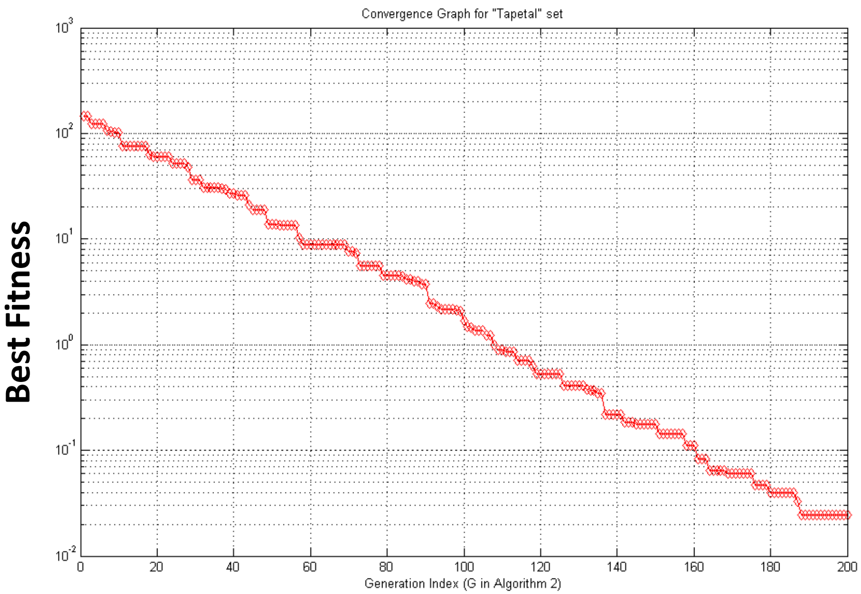
Comparison With Other Methods

Table 3. Comparison of our proposed DE based model with two traditional approaches demonstrates that our system provides a greater improvement to the accuracy and time efficiency of SEM rotation estimation. Here, we investigate and compare our method with ADBA and ASDBA techniques. We labeled our proposed method as **DE**.

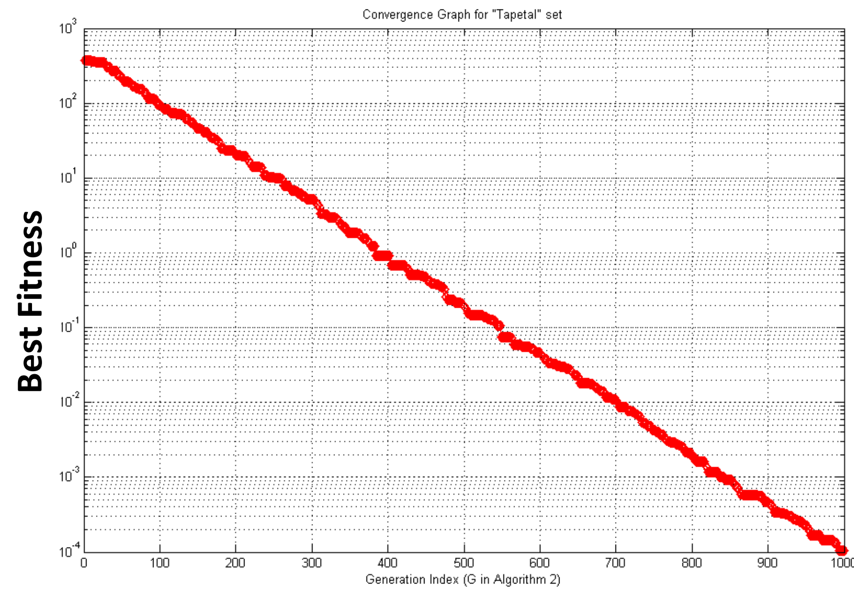
Method	Image set	Total Matches	Rotation angle	ΔR	Elapsed time
ADBA	tapetal cell	509	9 degrees	7.39E-02	21.74 Sec.
ASDBA	tapetal cell	509	9 degrees	9.86E-03	16.18 Sec.
DE	tapetal cell	509	9 degrees	5.07E-04	9.18 Sec.
ADBA	diatom frustule	286	30 degrees	1.94E-02	12.48 Sec.
ASDBA	diatom frustule	286	30 degrees	6.19E-02	9.83 Sec.
DE	diatom frustule	286	30 degrees	7.41E-04	4.97 Sec.

Experimental Validations

Convergence Graph (Contd.)



A **Generation Index (G in DE Algorithm)**

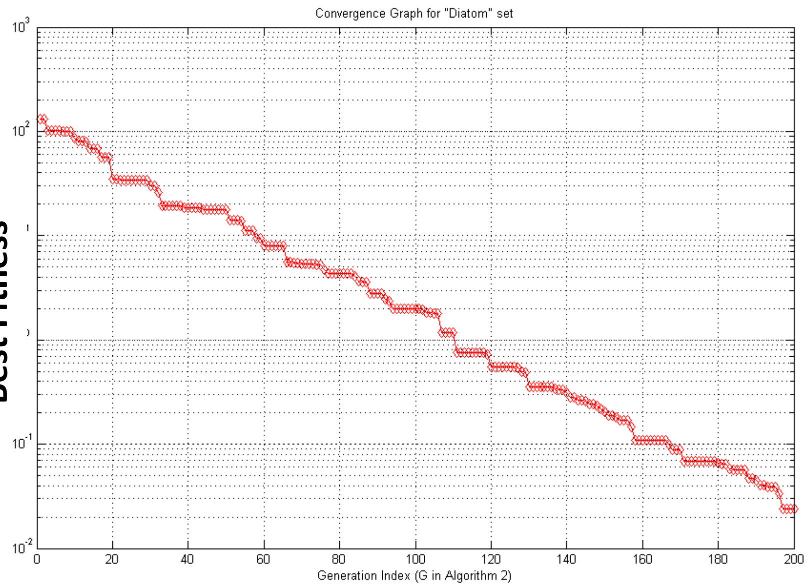


B **Generation Index (G in DE Algorithm)**

Fig 9. Convergence graph comparison for the "*Tapetal*" set. In this experiment we only used two images tilting by 9 degree with 509 3D points. (A) and (B) show the results on a different number of generations obtained with G=200 (A) and G=1000 (B).

Experimental Validations

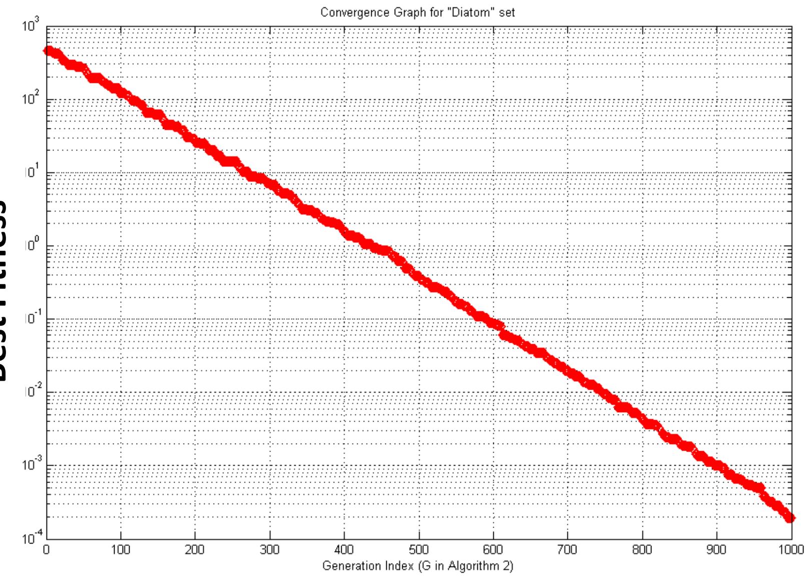
Convergence Graph



Best Fitness

A

Generation Index (G in DE Algorithm)



Best Fitness

B

Generation Index (G in DE Algorithm)

Fig 10. Convergence graph comparison for the "*Diatom*" set. In this experiment we only used two images tilting by 15 degree with 317 3D points. (A) and (B) show the results on a different number of generations obtained with G=200 (A) and G=1000 (B).

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Experimental Validations

Accuracy in 3D Modeling (Contd.)

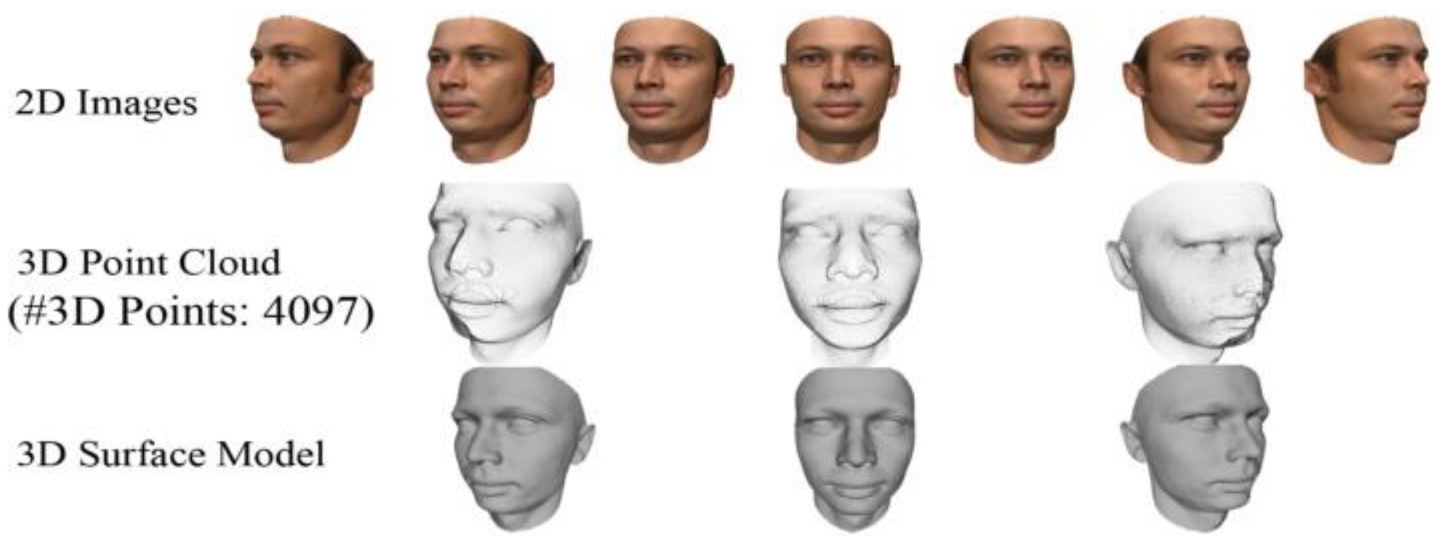

Fig 11. A set of seven 2D images of the synthetic "Face" model along with its 3D shape structure are shown in this figure. These images were tilted 10 degrees from one to the next in the image sequence. 4097 3D points were used in the experiment to compare the accuracy on 3D shape modeling. Comparing results are shown in Table 4.

Experimental Validations

Accuracy in 3D Modeling

Table 4. Hausdorff Distance unit calculations on the synthetic *"Face"* Model. We called our method as **DE**.

Method	Number of 3D Points	HDu (min)	HDu (max)	HDu (mean)
ADBA	4097	0.000000	0.077471	0.041309
ASDBA	4097	0.000000	0.067120	0.009711
DE	4097	0.000000	0.032709	0.003961

Conclusion and Future Work

- Our approach combines Projective Geometry with Differential Evolutionary algorithm to restore the 3D surface model of various objects from micro size to macro.

- The main focus of this research project was to increase the reliability and accuracy of SEM 3D surface reconstruction from multiple views.

- The present work is expected to bridge the gap between microscopy imaging and computer vision community, opening the doors for different interesting directions from the computer vision community to this fast-growing application area.

- Future direction would be to increase the robustness of the algorithm by better handling the matching points at the first step to get rid of the outliers, increasing the speed of the process.

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Thank you!

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