SEM 3D Surface Reconstruction

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SEM 3D Surface Reconstruction; What and Why?

Restoring back the 3D surface model of a microscopic object is extremely difficult to solve while its three dimensional shape in a real world is only projected into 2D digital images using a Scanning Electron Microscope (SEM). Computer vision exposes a great ability to restore the geometry of the scene by solving the inversion problem going from 2D to 3D.

The field of 3D surface modeling of microscopic objects will offer **quantitative** and **visual information** for a variety of applications such as medicine, genetic, pharmacology, chemistry, and mechanics. Examples include:

1) Biological researchers planning to get 3D surface model of biological samples to investigate their surface attributes, recognizing the shape model of a cell.
2) Mechanical researchers designing a micro widget which needs to fit into a micro gadget.

OBJECTIVES

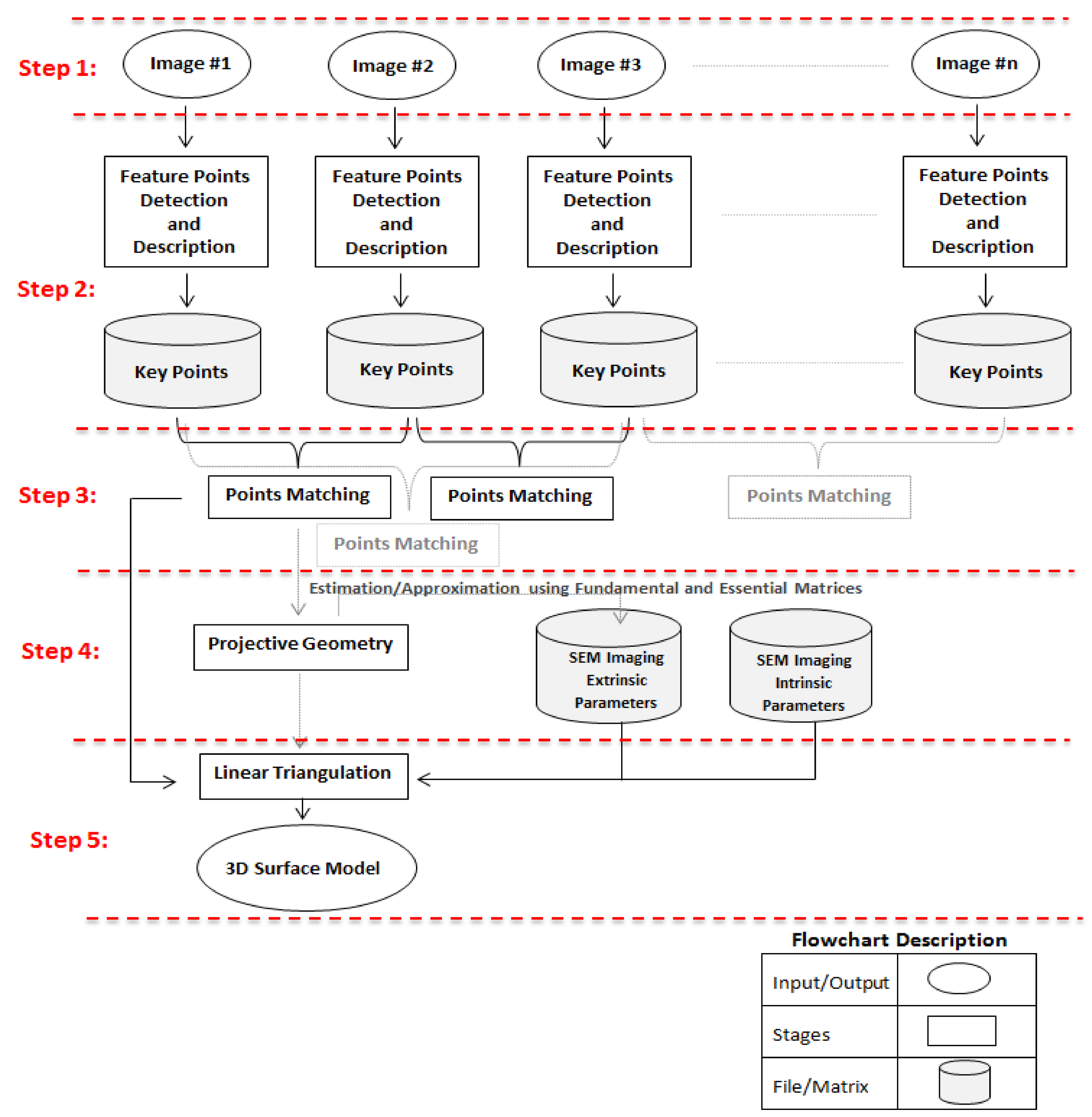
- To bring 3D technology for microscopic objects.
- To create realistic anatomic shape from microscopic objects.
- To allow rotation and depth for further interpretation of microscopic objects.

APPROACH

- The pipeline of SEM 3D surface reconstruction has basically five steps:

1) Take a set of digital images from a micro object.
2) Identify keypoints in the images that can possibly be detected in other images in the set.
3) Search for corresponding points in images.
4) Using projective geometry theory to estimate rotation and translation.
5) After estimating the relative position and orientation of the images, the 3D location of all matching points can be reconstructed by triangulation.

- We normally initialize the 3D points and relative poses with some error thresholds [1]. The latter process is a minimization routine that optimizes the 3D geometry information and rotation/translation parameters together. Block diagram of SEM 3D surface reconstruction is shown here:



METHODOLOGY

- The major part of our work is on a refinement process by defining a cost function for any set of parameters (3D points and relative poses). For instance, if we are given two 2D images with N matching points (x^i, i=1,2,…N), then the goal is to estimate six parameters for modeling the object motion (rotation and translation) and N*3 for the 3D points X_i by minimizing the following projection error:

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

- Parameterization the space of rotation and translation is the most important portion of the problem. We define the translation vector of the second position with respect to the first one as $t = (t_x, t_y, t_z)^T$. In order to have better flexibility, the quaternion parameterization is applied to 3D rotation representation. A quaternion Z = a+bi+cj+dk, where a, b, c, and d are real numbers and $i^2 = j^2 = k^2 = -1$ [1]. Z is a unit quaternion if and only if :

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

- Using the quaternion approach, rotation matrix representation could be as follow:

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

- By considering above equations, the parameterization of translation and rotation will be determine by seven dimensional vector as follow:

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

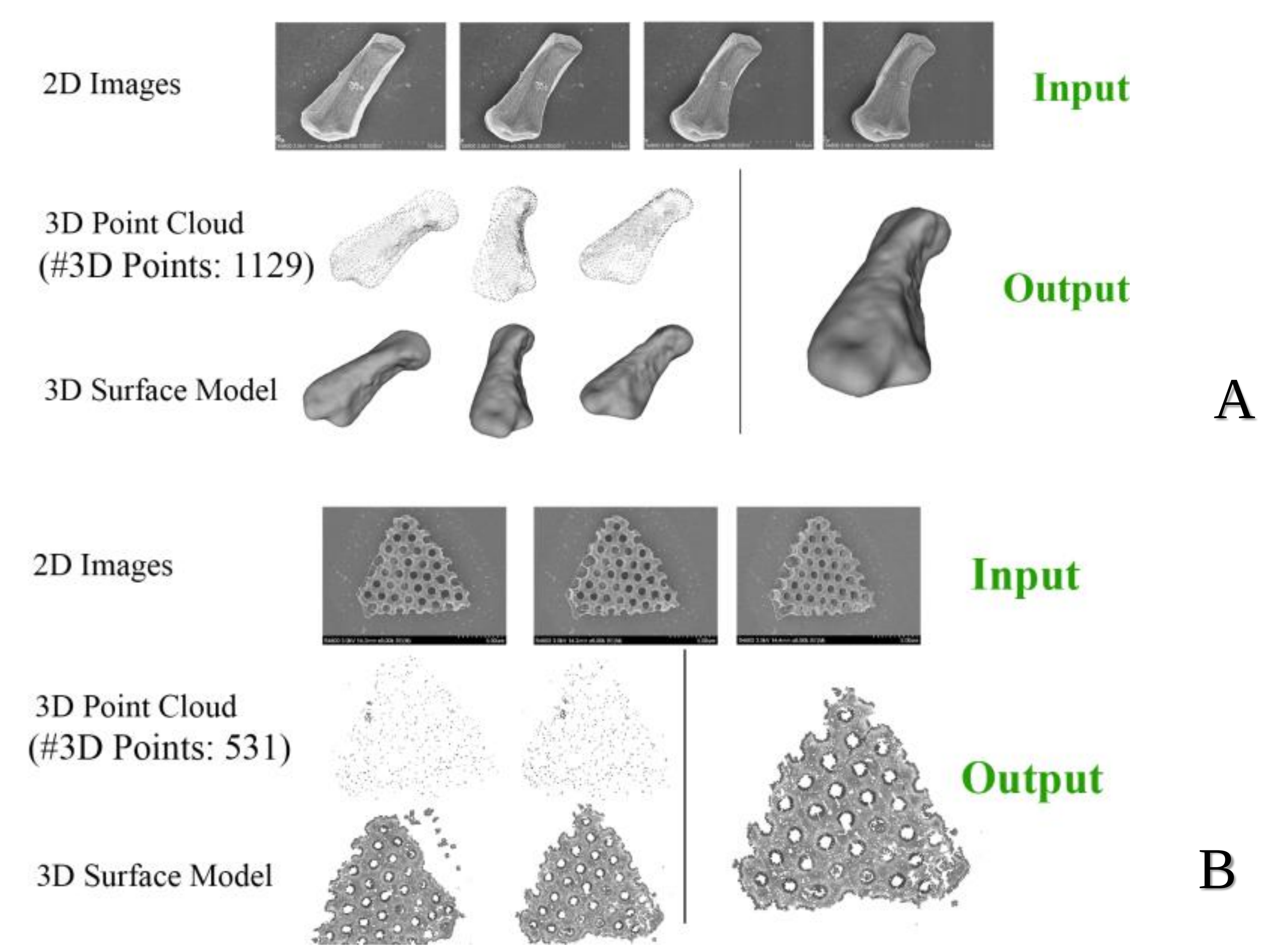
- The final parameterization will be:

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

- We took Differential Evolution algorithm into account to solve the above optimization problem.
- Differential Evolution (DE) is a genetic searching based minimization strategy using generated populations within the parameter space [2]. This method first generates an initial population randomly, then iteratively updates them to estimate the best possible values for an optimization problem. The initial population is modified from one generation to the others by using two major operators: 1) Mutation, and 2) Crossover [2].

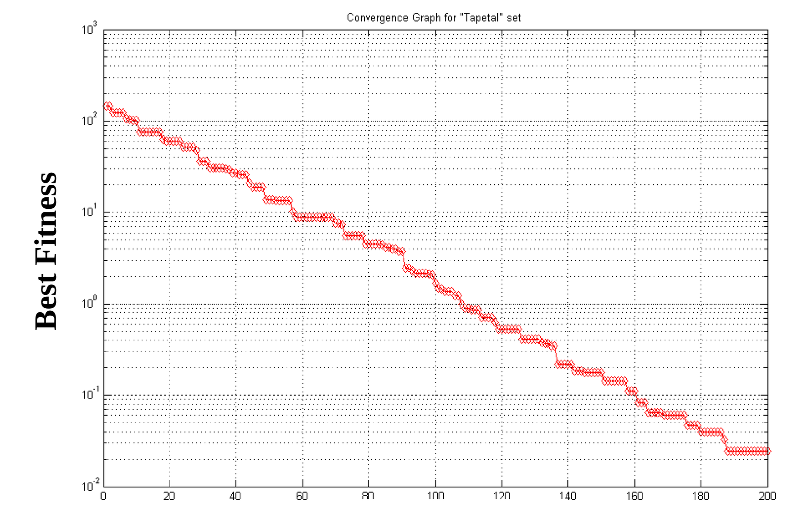
VISUALIZATION RESULTS

- **Visualization of SEM 3D surface reconstruction:** (A) shows 2D SEM images, 3D reconstructed point cloud and surface model of a *Tapetal* cell respectively. The *Tapetal* images obtained from a SEM by tilting 9 degrees from one to the next in the image sequence. (B) shows three 2D SEM images of a *Diatom* which were taken by tilting 15 degrees. 3D point cloud and 3D reconstructed surface model of the *Diatom* are presented as well.

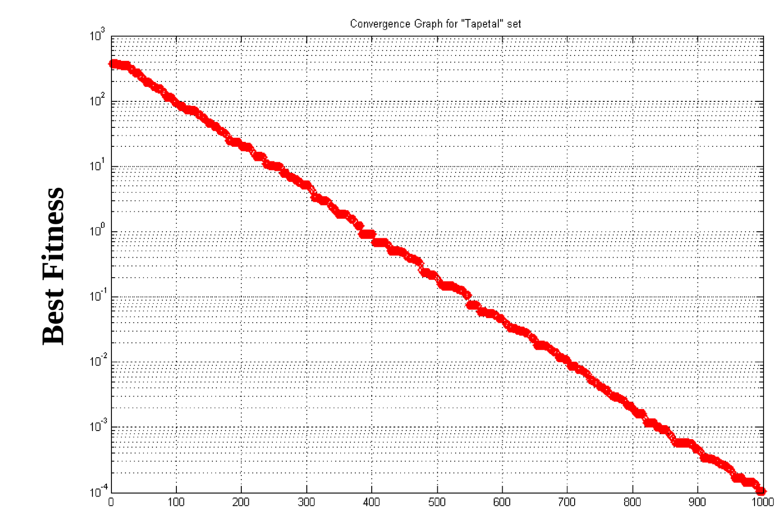


OPTIMIZATION RESULTS

- **Convergence and error range:** convergence rate for the *Tapetal* set with respect to different number of generations in our proposed algorithm is shown in the following charts. The 3D rotation estimation error ranges from 5.02E-04 to 2.95E-03, mostly depending on the G_{max}.



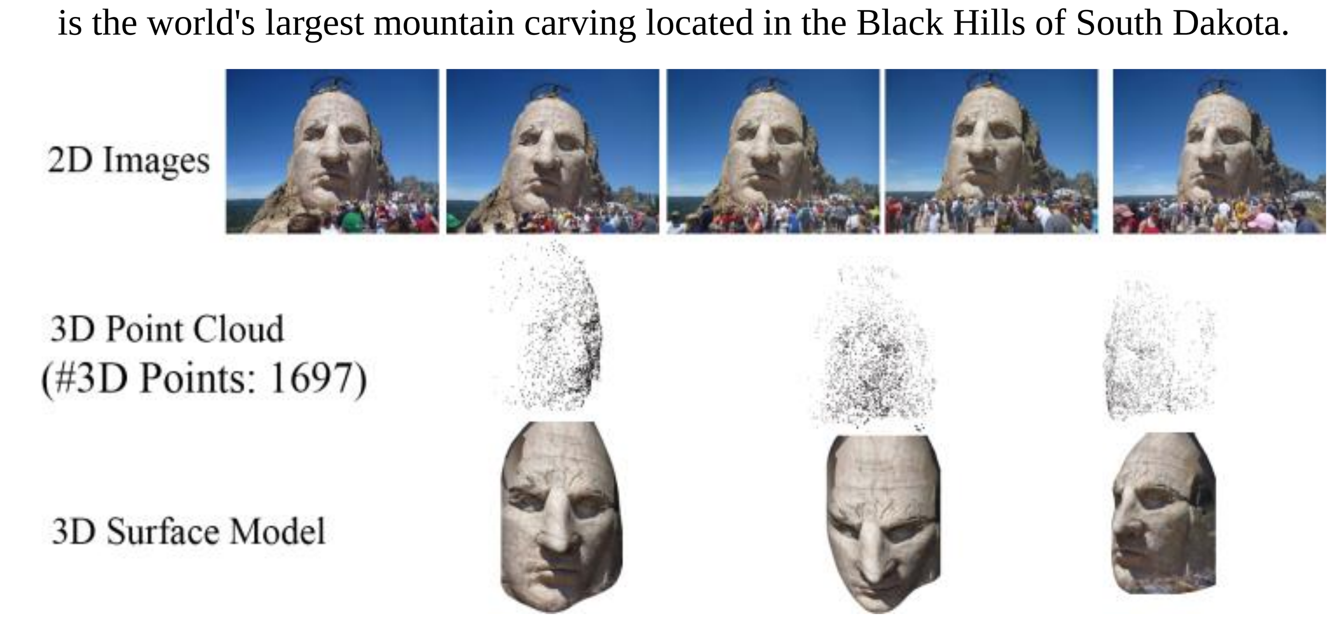
G_{max}= 200



G_{max}= 1000

3D Reconstruction from Micro to Macro Objects

- We have also applied our proposed method on non microscopic objects. The below figures show the visualization of 3D surface model of Crazy Horse Memorial which is the world's largest mountain carving located in the Black Hills of South Dakota.



CONCLUSION AND FUTURE WORK

- Our approach combines projective geometry with differential evolution 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 in an accurate manner.
- Generated 3D shapes are originally visible by your screen . You never need any further accessories (i.e. 3D glasses).
- 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.

BIBLIOGRAPHY

[1] Hartely, R., Zisserman, A.: Multiple view geometry in computer vision. Cambridge University Pressy, UK (2004).

[2] Chakraborty, U.K.: Advances in Differential Evolution. Prentice Hall, USA (2008)

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