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Characterization of Aluminium Oxide Nanoporous Images using different Segmentation Techniques

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Abstract*: The characterizations of the nanoporous membrane require appropriate segmentation of the pores. The segmentation technique used for one category or class of image may not be suitably applied to the other class of images. Selecting the ubiquitous segmentation technique that can be applied to all image types is a challenging issue. In spite of several decades of research, there is no ubiquitously accepted method for image segmentation and therefore it remains a challenge in digital image processing. The objective of the present study is to automate the system with five different segmentation techniques; global thresholding, active contour, K-means, region growing and watershed to extort the pore from the experimental Al_2O_3 FESEM images, synthesized using different anodizing parameters. The geometrical features; nanopore wall thickness, pore size and porosity are computed for all the experimental images with the proposed segmentation techniques and are compared with the manual results. The variation in the proposed and manual results, referred to as error is computed. It is observed that the average error for the segmented pore characteristics using global thresholding, active contour, K-means, region growing and watershed are 7%, 14%, 13%, 18% and 20% respectively. The analysis predicts, error in using global thresholding segmentation technique is least, as compared to other methods and thus, it is considered the most appropriate segmentation technique among the five methods mentioned in the present study to segment the experimental Al_2O_3 FESEM images.

Keywords*: Active contour, Global thresholding K-means, Region growing, Watershed.

I. INTRODUCTION

Nanotechnology has captured every discipline of the industry and technology due to its versatile applications. These nano applications require customised membrane. The morphological investigation of these membranes majorly includes the characterization of nanopore shape, structure, porosity, pore density, regularity ratio etc.

This characterization with marginal and negligible error depends exclusively on the appropriate segmentation technique, which will aptly segment the nanopore under investigation in the Al_2O_3 FESEM images used in the experiment. In the current study five different segmentation techniques [12]; global thresholding, active contour, K-means, region growing and watershed are used to segment the nanopores in the Al_2O_3 FESEM experimental images. The geometrical features; nanopore wall thickness, pore size and porosity are computed for all the images using the above mentioned five different segmentation techniques. Further, the error, which is the absolute value of the difference in the manual and programmed values over the summation of the manual and the programmed values, is calculated to select the segmentation technique with least error among the five techniques. It is observed that the average error for the segmented pore characteristics using global thresholding, active contour, K-means, region growing and watershed are 7%, 14%, 13%, 18% and 20% respectively. The analysis predicts, error in using global thresholding segmentation technique is least, as compared to other techniques in the experiment and thus, it is considered the most appropriate segmentation technique among the five techniques used in the experiment.

For decades, the researchers have worked on various segmentation techniques. Obtaining nanostructure using global thresholding [1], time effect on Al_2O_3 [2] was presented by P. Bannigidad. Morphological segmentation of FIB-SEM data is proposed by T. Prill [3]. Dorothea B., worked on nanoporous Al_2O_3 membranes [4]. Watershed algorithm was implemented by Anton S. [5]. Haidar J. estimated the nanopore size [6]. T. Xiong worked on segmentation with spatial relationships [7]. M. Akhtaruzzaman automated threshold detection [8]. K-means clustering algorithm was demonstrated by N. Dhanachandra [9]. Itaru Yanagi worked on stable fabrication [10]. A two-dimensional (2D) nanoporous membrane was presented by Guo-Rong Xu [11]. Parashuram B processed the nanoporous images and cocci bacterial cells using image processing techniques [13-15].

II. MATERIALS AND METHOD

The top views of anodized Al_2O_3 FESEM images used in the proposed study are shown in Fig.1.

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Aluminium nanoporous FESEM images (A, B, C and D) are obtained at regular intervals of time (5 mins, 9 mins, 20 mins and 30 mins), keeping in constant the concentration (5%), temperature (20^0C) and voltage (50 V). The images (E, F and G) are obtained at varying voltage (35V, 40V, 45V) keeping the concentration (4.7%), time (8min) and temperature (5^0C) constant. Images (H and I) are obtained at 4% and 5% concentration, 20^0C and 25^0C temperature respectively keeping time (20 mins) and voltage (50V) constant.

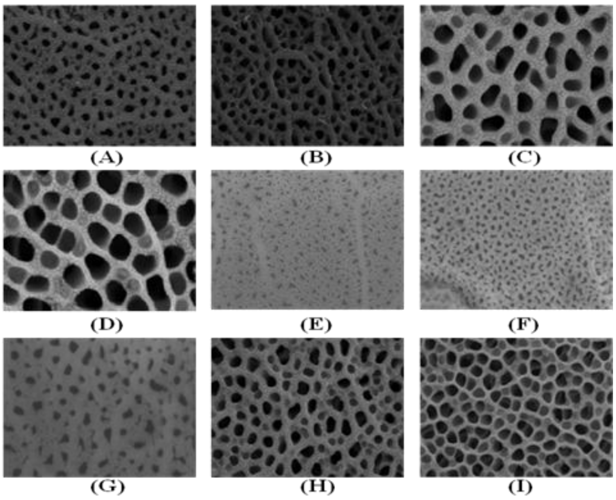


Fig. 1.Top view of Al_2O_3 FESEM images

A. Global Thresholding

Global thresholding is the most extensively used segmentation technique in digital image processing. It prominently extorts the foreground from the background and also converts the input image into a binarized image by selecting the threshold value, denoted as T. The operation is defined using the below function.

$$g(x,y) = \begin{cases} 0, & if\ f(x,y) < T \\ 1, & if\ f(x,y) \geq T \end{cases}$$

In the above function g(x,y) is threshold image and f(x,y) is input image.

B. Active Contour

Active contours also called as “snakes” are curves generated by the system to identify the object boundaries using the internal and external forces.

C. K-Means

K-Means divide the cluster of objects into K groups and then performs the below steps:

Step 1: Find the mean of each group.

Step 2: Calculate the distance for each point in every cluster from the corresponding cluster mean.

D. Region Growing:

Region growing technique use; splitting and merging approaches iteratively to identify the region of interest.

E. Watershed

This technique uses the following steps:

Step 1: Identify the objects that need to be segmented.

Step 2: Create foreground markers.

Step 3: Identify pixels that are not part of any object (background markers).

Step 4: Modify the segmentation function so that it only has minima at the foreground.

Step 5: Compute the watershed transform for the modified segmentation function.

III. PROPOSED METHOD

The objective of the present study is to develop automated algorithms that use global thresholding, active contour, K-means, region growing and watershed segmentation techniques to extract the nanopores from the Al_2O_3 FESEM images and compute the geometrical characteristics; wall thickness, poresize and porosity. Further, the proposed values are compared with the manual results and the variation in the results, referred to as an error is computed. The error for each characteristic is computed using equation (1).

$$\text{Error} = \frac{|Manual\ Result - Proposed\ Result|}{|Manual\ Result + Proposed\ result|} \qquad (1)$$

The porosity is defined using equation (2).

$$\propto = \frac{\pi}{2\sqrt{3}}\left(\frac{Dp}{Di}\right)^2 \qquad (2)$$

where;

D_p : Nanopore diameter

D_i : Interpore distance

The flow diagram for the proposed method is depicted in Fig. 2.

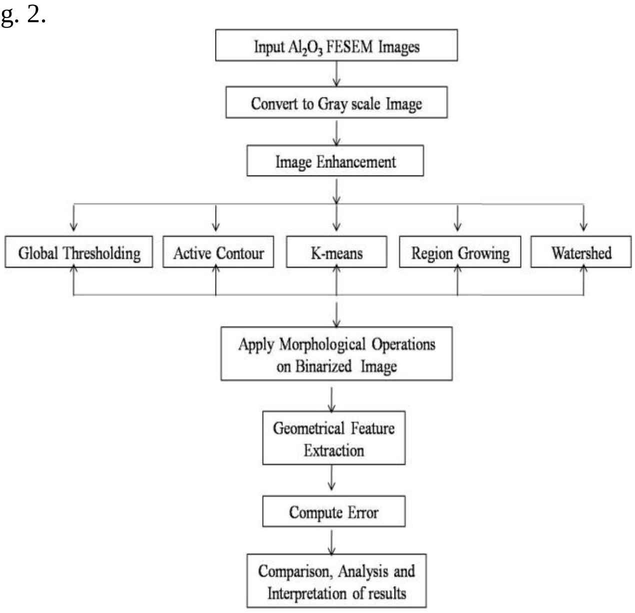


Fig. 2.Flow diagram for the proposed method

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The experimentation of the proposed study is implemented on Intel Core i3-6100 CPU @ 3.70GHz with 4 GB RAM using MATLAB R2010b software. Every Al_2O_3 FESEM image utilized in the investigation is captured at customary time (min) intervals, concentration (%), temperature (^{0}C) and voltage (V) (Fig. 1.). The input image is converted into a grayscale image and then enhanced. The enhanced image is further segmented using global thresholding (Fig. 3 (i)), active contour (Fig. 3 (ii)), K-means (Fig. 3 (iii)), region growing (Fig.3 (iv)) and watershed (Fig. 3 (v)) techniques.

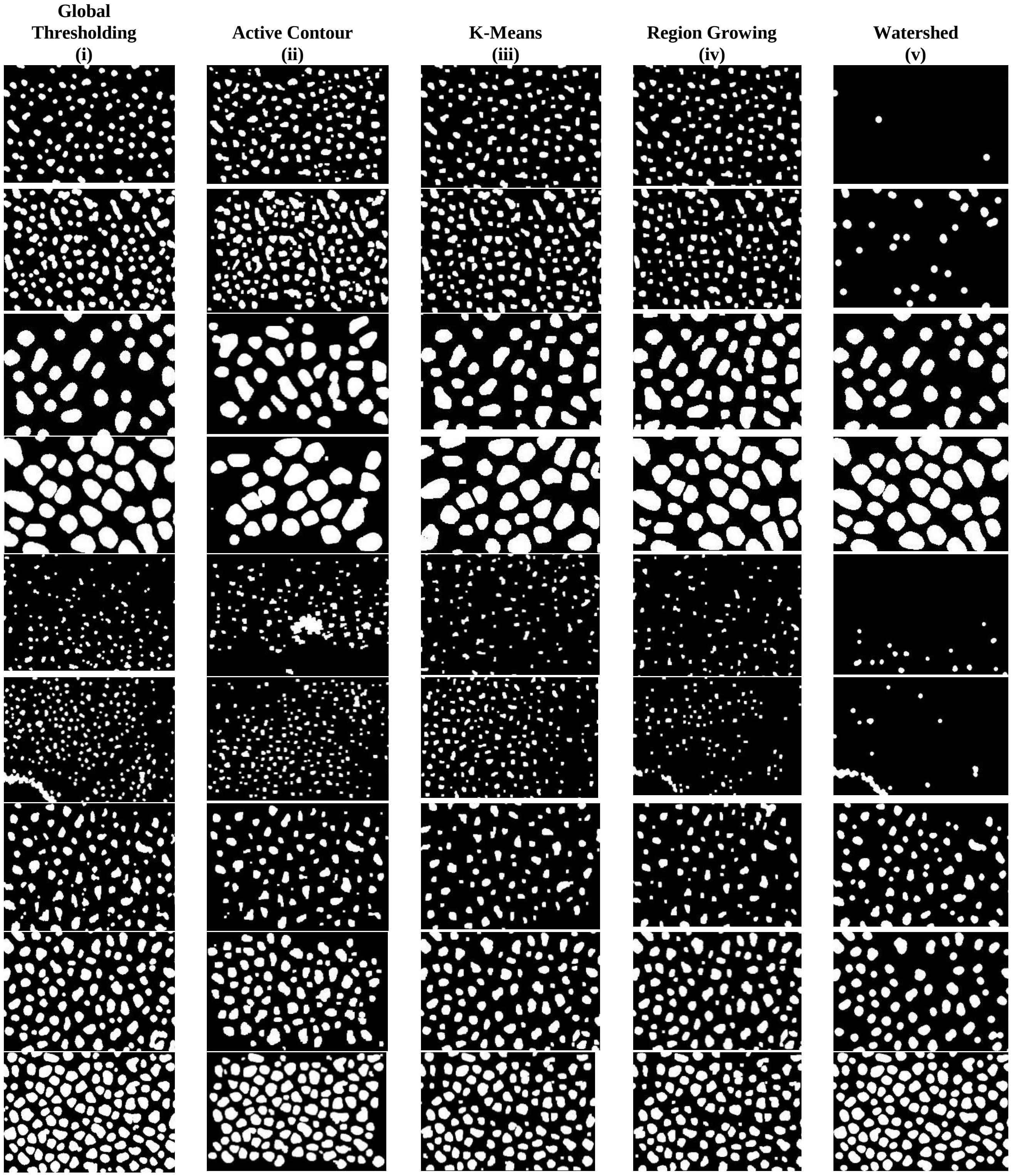


Fig. 3. Segmented images (i) Global Thresholding, (ii) Active Contour, (iii) K-Means, (iv) Region Growing, (v) Watershed

The binarized images obtained from the segmentation undergo the morphological operations and the geometrical features of the nanopores are obtained from every image (A to I). These values of nanopore wall thickness, nanopore size and porosity are tabulated in Table 1, Table 2 and Table 3 respectively. Further, the error for each geometrical characteristic in all the images for every segmentation technique is computed using equation (1). The calculated error for nanopore wall thickness, nanopore size and porosity for all the images with different segmentation technique is projected in Table 4, Table 5 and Table 6 respectively. The graphical representation of error in each characteristic and average error in each segmentation technique is depicted in Fig. 4 and Fig. 5 respectively. It is observed that the average error in segmentation using global thresholding, active contour, K-means, region growing and watershed are 7%, 14%, 13%, 18% and 20% respectively.

The analysis predict, error in using global thresholding segmentation technique is least, as compared to other techniques in the experiment and thus, it is considered the most appropriate segmentation technique among the five techniques used in the experiment.

Table-I: Nanopore wall thickness for different segmentation technique

Images	Nanopore Wall Thickness (nm)					
	Manual	Global Thresholding	Active Contour	K-Means	Region Growing	Watershed
A	58	59.00	48.71	49.92	49.92	40.02
B	56	57.00	45.36	45.00	45.36	42.01
C	48	49.00	33.77	39.05	40.83	39.11
D	26	51.00	27.12	37.12	35.54	32.56
E	35	34.94	34.76	34.77	33.00	31.54
F	50	50.09	41.58	40.83	26.16	36.15
G	46	45.36	45.84	47.76	47.00	41.96
H	52	52.13	52.58	54.12	54.47	51.57
I	58	58.75	50.00	51.30	51.15	52.17

Table-II: Nanopore size for different segmentation technique

Images	Nanopore Size (nm)					
	Manual	Global Thresholding	Active Contour	K-Means	Region Growing	Watershed
A	32	32	40.87	33.99	34.02	24.26
B	54	34.74	47.81	38.03	36.49	43.78
C	58	61.25	105	49.34	52.18	52.69
D	81	78.62	117.72	66.92	67.61	73.36
E	18	17.11	27.51	29.65	27.94	38.26
F	30	29.88	22.65	29.43	19.66	78.29
G	41	40.69	44.3	37.31	35.15	69.46
H	55	55.98	62.93	55.01	55.09	59.78
I	83	83.63	68.11	54.99	54.15	68.28

Table-III Porosity for different segmentation technique

Images	Porosity (%)					
	Manual	Global Thresholding	Active Contour	K-Means	Region Growing	Watershed
A	0.28	0.35	0.81	0.59	0.59	0.01
B	0.84	0.38	1.34	0.93	0.72	0.48
C	1.33	1.21	1.44	1	1.25	1.03
D	8.81	2.03	1.74	1.39	1.48	1.59
E	0.41	0.44	0.47	0.31	0.22	0.25
F	0.8	0.81	0.52	0.57	0.07	0.29
G	0.77	0.76	0.66	0.51	0.42	0.65
H	1.01	1.12	1.36	1.06	1.13	1.01

I	1.86	1.86	1.89	1.34	1.33	1.62

Table-IV Error in nanopore wall thickness

Images	**Nanopore wall thickness**									
	Global Thresholding		**Active Contour**		**K-Means**		**Region Growing**		**Watershed**	
	Error in value	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**
A	0.01	1%	0.09	9%	0.07	7%	0.07	7%	0.18	18%
B	0.01	1%	0.1	10%	0.11	11%	0.1	10%	0.14	14%
C	0.01	1%	0.17	17%	0.1	10%	0.08	8%	0.1	10%
D	0.32	32%	0.02	2%	0.18	18%	0.16	16%	0.11	11%
E	0	0%	0	0%	0	0%	0.03	3%	0.05	5%
F	0	0%	0.09	9%	0.1	10%	0.31	31%	0.16	16%
G	0.01	1%	0	0%	0.02	2%	0.01	1%	0.05	5%
H	0	0%	0.01	1%	0.02	2%	0.02	2%	0	0%
I	0.01	1%	0.07	7%	0.06	6%	0.06	6%	0.05	5%
Error	**0.04**	**4%**	**0.06**	**6%**	**0.07**	**7%**	**0.09**	**9%**	**0.1**	**10%**

Table-V Error in nanopore size

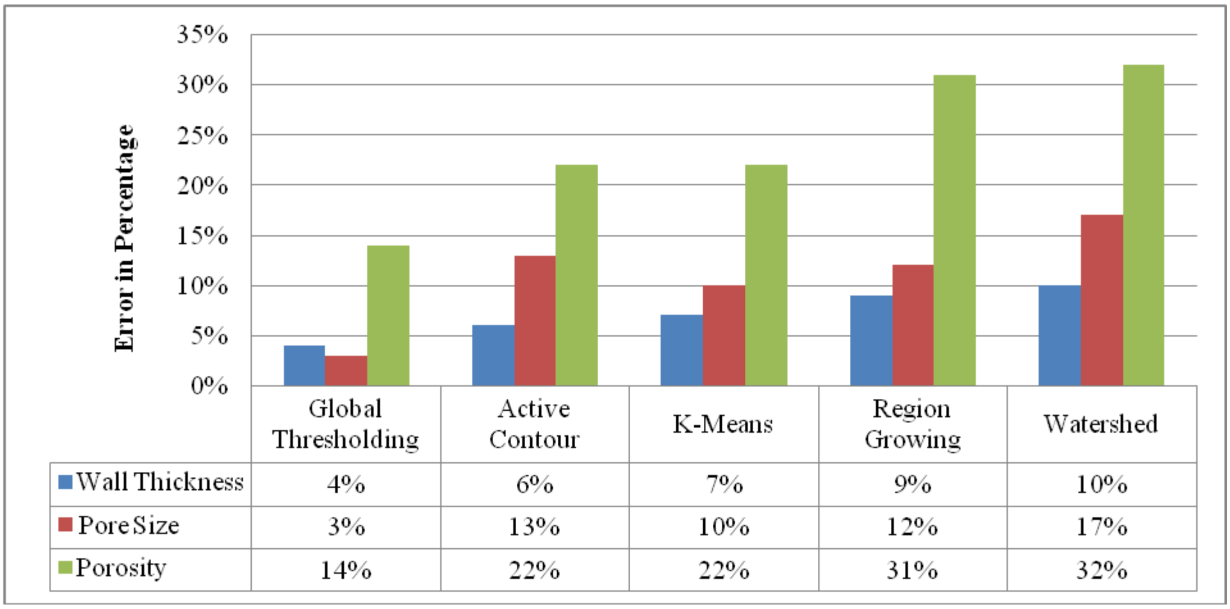
Images	**Nanopore size**									
	Global Thresholding		**Active Contour**		**K-Means**		**Region Growing**		**Watershed**	
	Error in value	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**
A	0	0%	0.12	12%	0.03	3%	0.03	3%	0.14	14%
B	0.22	22%	0.06	6%	0.17	17%	0.19	19%	0.1	10%
C	0.03	3%	0.29	29%	0.08	8%	0.05	5%	0.05	5%
D	0.01	1%	0.18	18%	0.1	10%	0.09	9%	0.05	5%
E	0.03	3%	0.21	21%	0.24	24%	0.22	22%	0.36	36%
F	0	0%	0.14	14%	0.01	1%	0.21	21%	0.45	45%
G	0	0%	0.04	4%	0.05	5%	0.08	8%	0.26	26%
H	0.01	1%	0.07	7%	0	0%	0	0%	0.04	4%
I	0	0%	0.1	10%	0.2	20%	0.21	21%	0.1	10%
Error	0.03	3%	0.13	13%	0.1	10%	0.12	12%	0.17	17%

Table-VI Error in porosity

Images	**Porosity**									
	Global Thresholding		**Active Contour**		**K-Means**		**Region Growing**		**Watershed**	
	Error in value	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**	**Error in value**	**Error in percentage (%)**
A	0.11	11%	0.49	49%	0.36	36%	0.36	36%	0.93	93%
B	0.38	38%	0.23	23%	0.05	5%	0.08	8%	0.27	27%
C	0.05	5%	0.04	4%	0.14	14%	0.03	3%	0.13	13%
D	0.63	63%	0.67	67%	0.73	73%	0.71	71%	0.69	69%
E	0.04	4%	0.07	7%	0.14	14%	0.3	30%	0.24	24%
F	0.01	1%	0.21	21%	0.17	17%	0.84	84%	0.47	47%
G	0.01	1%	0.08	8%	0.2	20%	0.29	29%	0.08	8%

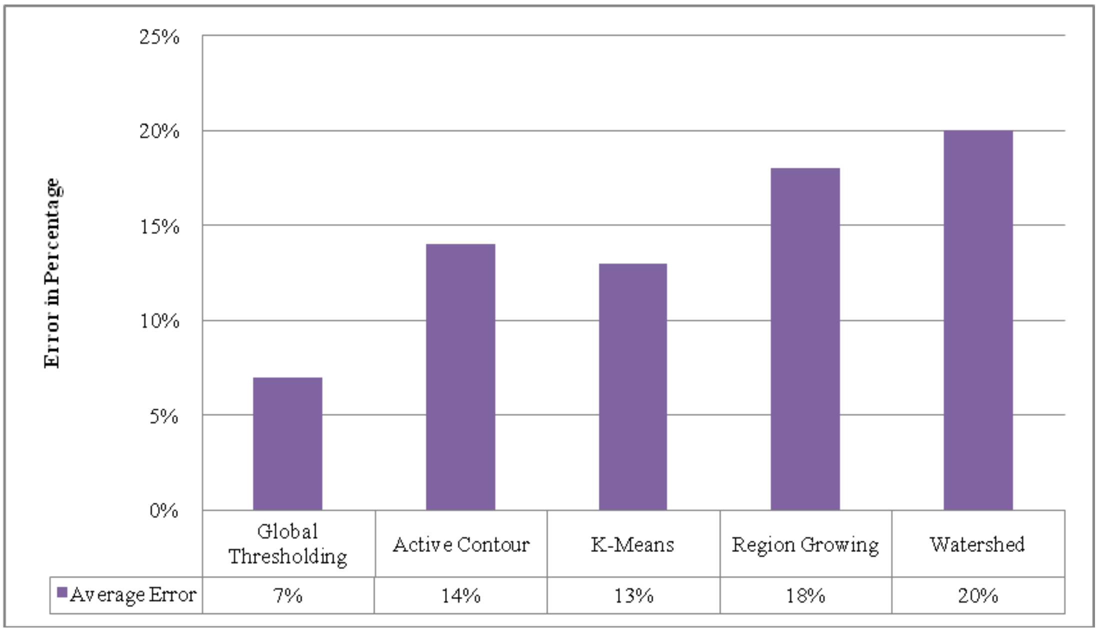
Table-VII Average error in the geometrical characteristics of the nanopores for different segmentation techniques

Geometrical Characteristics	Global Thresholding		Active Contour		K-Means		Region Growing		Watershed	
	Error in value	Error in percentage (%)	Error in value	Error in percentage (%)	Error in value	Error in percentage (%)	Error in value	Error in percentage (%)	Error in value	Error in percentage (%)
Wall Thickness	0.04	4%	0.06	6%	0.07	7%	0.09	9%	0.1	10%
Pore Size	0.03	3%	0.13	13%	0.1	10%	0.12	12%	0.17	17%
Porosity	0.14	14%	0.22	22%	0.22	22%	0.31	31%	0.32	32%
Average Error	**0.07**	**7%**	**0.14**	**14%**	**0.13**	**13%**	**0.18**	**18%**	**0.2**	**20%**



	Global Thresholding	Active Contour	K-Means	Region Growing	Watershed
🟦 Wall Thickness	4%	6%	7%	9%	10%
🟥 Pore Size	3%	13%	10%	12%	17%
🟩 Porosity	14%	22%	22%	31%	32%

Fig. 4. Error in individual characteristics for different segmentation techniques



	Global Thresholding	Active Contour	K-Means	Region Growing	Watershed
🟪 Average Error	7%	14%	13%	18%	20%

Fig. 5. Average error in different segmentation techniques

V. CONCLUSION

The objective of the present study is to automate the system with five different segmentation techniques; global thresholding, active contour, K-means, region growing and watershed to extort the pore from the experimental Al_2O_3 FESEM images, synthesized using different anodizing parameters. The geometrical features; nanopore wall thickness, pore size and porosity are computed for all the experimental images with the proposed segmentation techniques and are compared with the manual results. The variation in the proposed and manual results, referred as error is computed. It is observed that the average error for the segmented pore characteristics using global thresholding, active contour, K-means, region growing and watershed are 7%, 14%, 13%, 18% and 20% respectively. The analysis predict, error in using global thresholding segmentation technique is least, as compared to other methods and thus, it is considered the most appropriate segmentation technique among the five methods mentioned in the present study to segment the experimental Al_2O_3 FESEM images.

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