Boron Nanoparticle Image Analysis using Machine Learning Algorithms

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Abstract

The effort of digital image processing involves efficient computation aimed at developing an economical, faster and more accurate, and cost-effective automated system. The objective of this paper is to ascertain and categorize Boron nanoparticles (BNP) using digital image processing techniques. The spatial features are unsheathed from the Boron nanoparticle Transmission Electron Microscope (TEM) images using different segmentation techniques, namely; Fuzzy C -means (FCM) and K-means. The size of Boron nanoparticles is determined and categorized based on the area(size) in the microsize.The synthesization and characterization of Boron nanoparticles play an important role as an elementary procedure for the formation of Boron nanoparticles. The results are analyzed, interpreted and comparison is done with the manual values to observe the efficacy of the results. It is observed that the K-means segmentation technique yields a smaller amountof error (5.87%) as compared with Fuzzy C-mean(16.78%). Hence, it is considered that the K-Means is the most relevant segmentation technique for Boron nanoparticle image analysis and categorization. The statistical test of significance is applied using the Chi-square testing method (at 5% of significance level) to check the relationship between the manual results and the algorithm results.The proposed study also establishes collaborative research work between Chemistry and Computer Science departments to develop computational research on these platforms.

Keywords: Boron; Synthesization; Characterization; Nanoparticle; Image analysis; Image segmentation; TEM; FCM; K-Means.

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1. Introduction

With the emerging innovations in nanotechnology, researchers and scientists have found the applications of nanoparticles in various fields such as food science, material science, electronics and IT applications, medical and healthcare, energy, and environmental remediation, etc., The unexpected behavior of nanoparticles often creates a great challenge in the prediction of the size of Boron nanoparticles. Heiligtaget.al.[1]experimented that,strongly-size related properties of nanoparticles offers innumerable discoveries. The formation of Boron nanoparticles depends on the effective process of synthesization and characterization using chemical and technical methods. Zhang et. al.[2] have proposed the synthesis and characterization of Boron-Nitradenanocages which forms the basis for the present study.The synthesization includes a chemical process that uses a mixture of diborane (B_2H_6) and nitrogen (N_2) to which a certain amount of voltage is applied to form Boron nanoparticles, these nanoparticles are used for room temperature hydrogen generation from the water was carried out by Parham Rohani et. al.[3]. Boron nanoparticles are of great interest in neuron capture therapy of cancer cells has been proposed by Wittig et. al.[4]. ShreyanshTatiyaet. al.[5] have proposed the unique properties of the boron compounds: boron carbide (B_4 C), boron nitride (BN), also described the subsequent synthesis routes and the challenges associated with Boron nanoparticles. Alexandra et. al.[6] have proposed that the Boron nanoparticles can also be synthesized using room temperature without using flammable boranes. Tanya Makkaret. al.[7] have proposed a computer vision-based analysis for deficiency of Boron and Calcium by using an SVM classifier. Luz et.al.[8] have used texture-based image analysis of pattern classification to identify the Boron deficiency on growth of maize crops. Balasubramanium et.al.[9] have used intuitionistic fuzzy C-means clustering and also used multiple algorithms such as K-Means, Fuzzy K-means, principal component analysis (PCA), regularized expectation maximization (REM), FCM without imputation (FCMWT), FCM with imputation (FCMWI) for analyzing nutrient deficiency in incomplete crop images. SahatSimbolonet. al.[10]have proposed the use of digital image processing in analysis by using X-ray images of spectra lines of Boron and cadmium. Bannigidad et.al.[11]have proposed automated algorithms namely; Global thresholding, Active Contour, K-Means, Region growing, and Watershed segmentation techniques for the extraction of nanopores from Al_2O_3 FESEM images. The present study uses various segmentation techniques as K-means and Fuzzy C-Means. Xindonget.al.[12] proposed that the K-means is a partitional clustering method that partitions a given dataset into a pre-specified number k of clusters. Das[13] experimented the Fuzzy-based clustering where one can know if data objects are fully or partially belong to the clusters based on their memberships in different clusters Bannigidad et.al.[14] focused on nano-membrane engineering, imaging, and its characterization using an automated system by applying digital image processing techniques for the characterization of Aluminium oxide nanopores. Bannigidad et.al.[15] have proposed an automatic tool to determine the effect of time on nanopore structures using Al_2O_3 Field Emission Scanning Electron Microscope (FE-SEM) and Energy Dispersive Spectroscopy (EDX) nanopore images. The size analysis of Silver Nanoparticle (AgNps) images using Fuzzy C-means and K-Means techniques is proposed by Bannigidad. et.al.[16].

In this paper, the analysis and measurement of the size of nanoparticlesare made from Boron TEM images, which were obtained from the synthesization and characterization process done in the Dept. of Chemistry, Rani Channamma University, Belagavi. The geometrical feature area(size) is extracted for each nanoparticle using various segmentation techniques. Further, these nanoparticles are used in divergent applications. The sample TEM images of Boron nanoparticles are given in Fig.1.

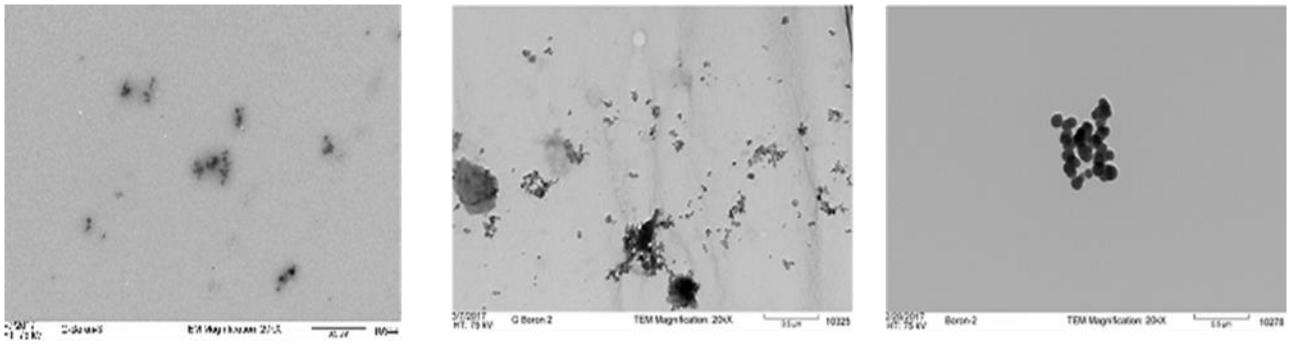

Fig. 1: TEM images of Boron nanoparticles

2.Materials and methods

The sample TEM images of Boron nanoparticles were obtained based on the synthesization and characterization process which are described as below:

2.1 Synthesis

The synthesis process of Boron nanoparticles is carried out at the Dept. of Chemistry, Rani Channamma University, Belagavi, using the following process;in the synthesization process, a mixture of diborane (B_2H_6) and nitrogen (N_2) is induced into a chamber a voltage of 20 to 30 v was applied between cathode and anode for evaporation. The deposits on the water-cooled wall of the chamber were collected. The deposits were laid down on an aluminum oxide crucible and then heated to 1073 K for 4 hours. Finally, the sample was cooled down to room temperature under pure N_2.The characterization is done in the Indian Institue of Science Bangalore based on this synthesis process. The characterization is done in the Indian Institute of Science, Bangalore, based on this synthesis process.

2.2 Characterization

Transmission Electron Microscopy (TEM) is used to analyze the size and morphology of the synthesized Boron nanoparticles and the X-ray diffractometer technique is used to examine the structural parameter and phase purity of synthesized Boron nanoparticles. For the TEM observations, the samples were prepared in two steps; as the beginning step, the deposit was dispersed in ethanol in an ultrasound bath, with the help of a drop of the suspension is transferred onto a carbon-coated TEM mesh grid and the ethanol was allowed to evaporate. In the second step, these samples were examined by an instrument JEOL 2000EX TEM, and XRD spectra were recorded at room temperature with the help of adiffractometer.Finally,the Boron TEM images are obtained and used for further study

3. Proposed Method

The objective of the proposed method provides an automated tool to determine the size and structure of the Boron nanoparticles in nanosize depending on the applications. The analysis also observed that the synthesization and characterization process is important for the formation of nanoparticles. Based on this synthesis process the TEM images of Boron nanoparticles were obtained and these TEM images contain noise and debris. To remove this debris the preprocessing operation namely;gamma correction has been applied, followed by various segmentation techniques; Fuzzy C-Means and K-Means to bifurcate foreground and background objects in the image. The morphological operations; dilation and erosion are applied to these segmented images to remove the noisy pixels and smoothen the edges of particles It is observed that the segmentation techniques Fuzzy C-meansmethod has variation when compared with the manual values, whereas the other segmentation technique, K-Means showed better results in comparison with the manual values. The flow diagram of the proposed method is shown in Fig. 2

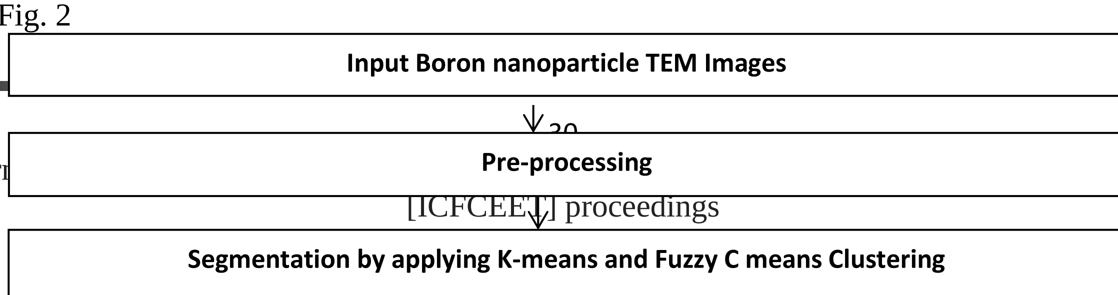

Fig. 2: Flow diagram of the proposed method

Algorithm: Segmentation, feature extraction, and categorization of Boron nanoparticles.

1: Read the Boron nanoparticle TEM image.
2: Perform preprocessing operations on the input image
(enhancement, applying filters, gamma correction)
3:Perform segmentation by applying K-means and Fuzzy C-means clustering methods and label the objects.
4: Apply Dilation and Erosion on the image in step 3
5:Extraction of geometric feature value; area(size) for all the Boron nanoparticles and store them in the knowledge base
6: Repeat steps from 1 – 5 for all segments.
7: Extracted nanoparticles are categorized based on the following condition:
if the area(size) is between is 0-100 µm, then it is normal
else if the area(size) is > 100 µm, then it is as enlarged**.**

4. Experimental Results and Discussion

The experimental study involves a total of 173 Boron nanoparticle images which were obtained from the synthesization process, which was done in the Dept. of Chemistry, Rani Channamma University, Belagavi. The synthesis and characterization process of these samples are discussed in Section2.The proposed experimentation is carried out on Intel(R) Core™ i5-10210U CPU@1.60GHz using MATLAB R2018a. The input image (Fig.3 (i)) is converted to grayscale and Gamma correction is applied (Fig.3 (ii)) to remove the noise present in the image. Fuzzy C-means clustering technique is applied as a segmentation method (Fig.3 (iii)) to identify a group of similar pixels that belongs to the same group or a specific region, which are different from other regions. Then, morphological dilation operation is applied which uses a structuring element for probing and expanding the nanoparticles contained in the input image Fig.3 (iv) followed by another morphological operation known as erosion which uses a structuring element for probing and reducing the shapes contained in the dilated nanoparticle images Fig.3 (v). Then each nanoparticle is extracted and labeled Fig.3 (vi). Finally, the geometrical feature values of each extracted nanoparticle are computed and stored for a knowledge base that can be used as a size-based

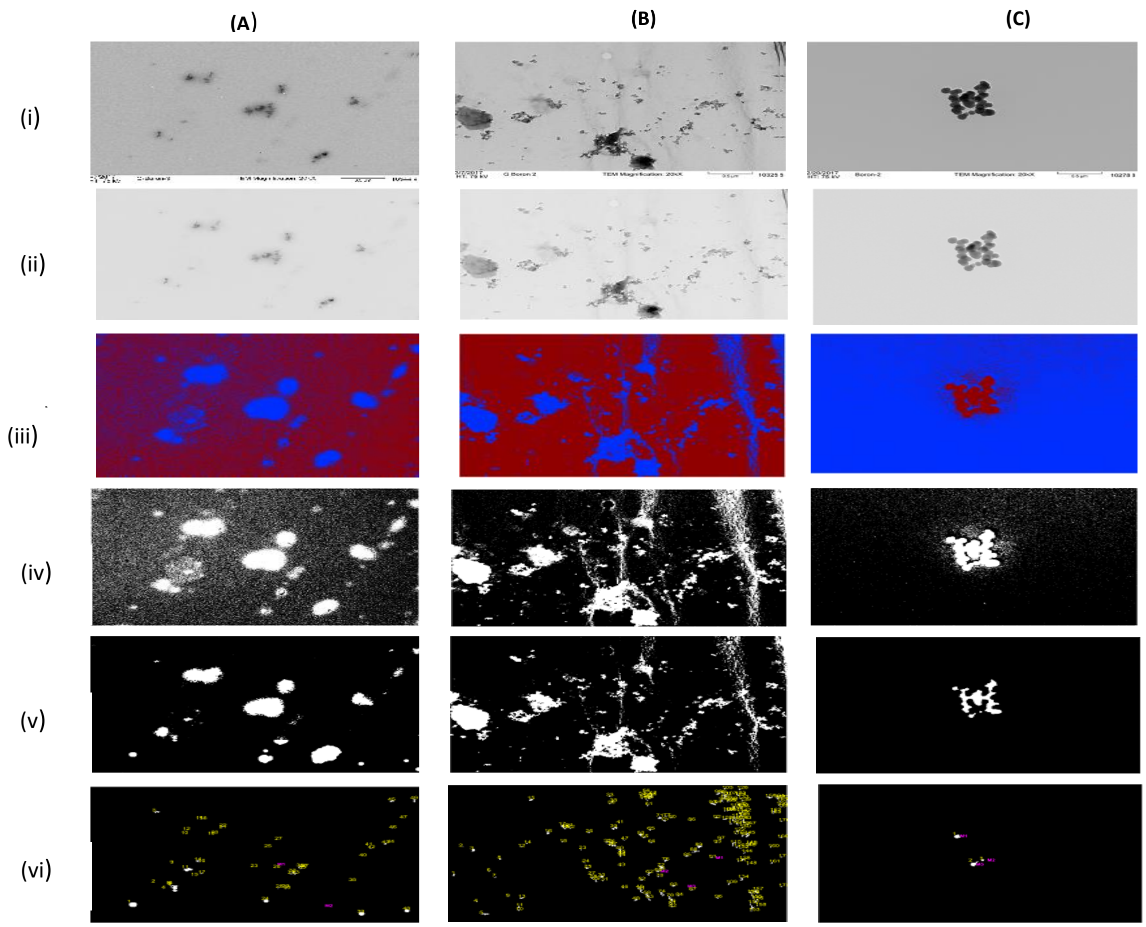

Fig. 3: Segmented images using the Fuzzy C-Means method. (i) Original Boron nanoparticles TEM images (ii) Gamma correction (iii) Fuzzy C-Means (iv) Dilation applied images (v) Erosion applied images (vi) Labeled images

application of Boron nanoparticles. Most of the applications of Boron nanoparticles are considered within the 100 µm and the rest of the nanoparticles have been extracted however are not often used. The nanoparticles are categorized based on the size of the area; 0 µm to 100 µm is considered normal, andgreater than 100 µm isconsidered enlarged. It is observed that the Fuzzy C-Means technique shows some error between manual and computed results, to test the robustness of the algorithm, we have used the K-Means clustering segmentation technique to obtain the size of Boron nanoparticles. K-means clustering technique reads the input Boron nanoparticle image Fig.4 (i), converted to grayscale images to which gamma correction is applied to remove noise presented in the input image Fig.4 (ii). Then, the K-means method is applied to these preprocessed images Fig.4 (iii) followed by morphological operation; dilation Fig.4 (iv) and erosion Fig.4 (v). The purpose of using dilation and erosion is to remove the noisy pixels and smoothen the edges of particles of the Boron TEM nanoparticle image.Individual Boron nanoparticles are extracted and labeled with manual values Fig.4 (vi). The nanoparticles are categorized based on the size of the area; 0 to 100 µm, and above 200 µm. The geometrical shape feature area(size) is computed for each labeled segment, and finally, the results are interpreted and analyzed in

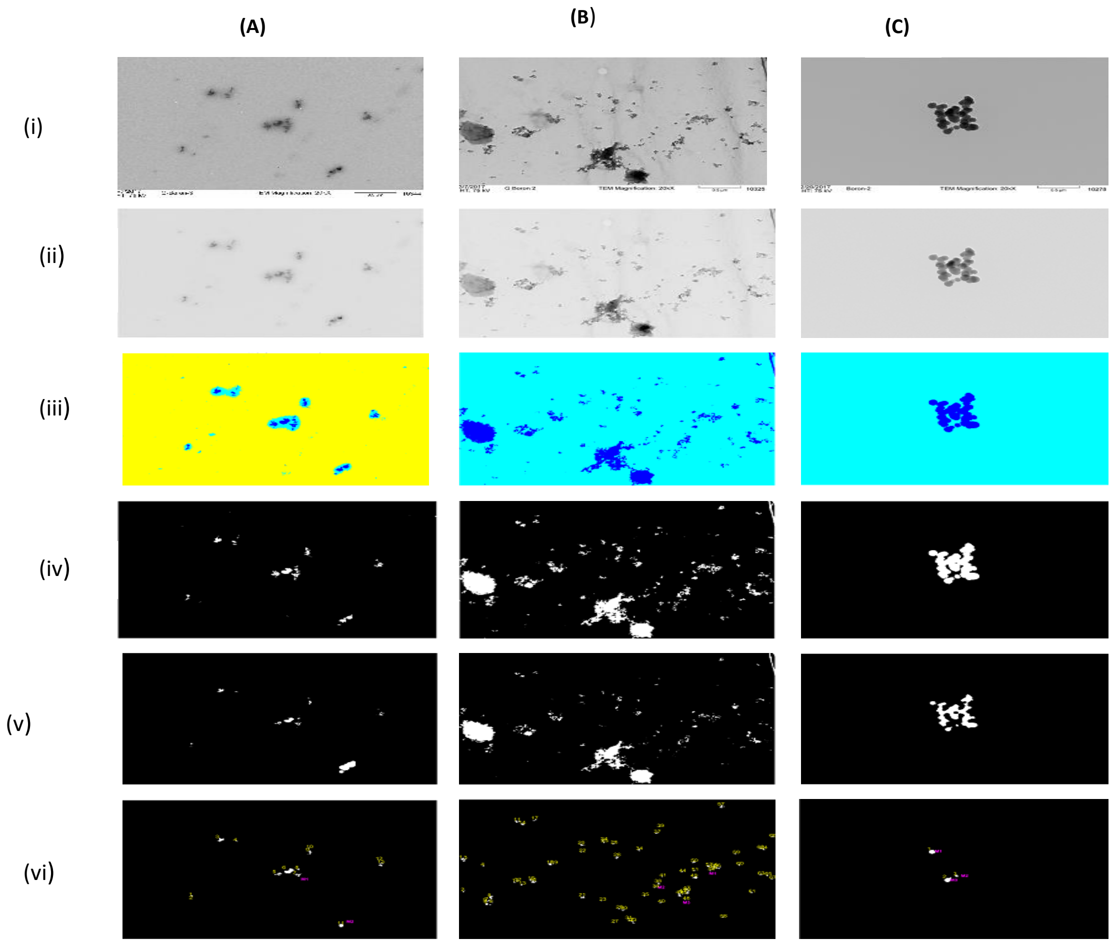

Fig. 4: Segmented images using the K-Means method. (i) Original Boron nanoparticles TEM images (ii) Gamma correction (iii) K-Means (iv) Dilation applied images (v) Erosion applied images (vi) Labeled images

comparison with manual results obtained from chemical experts for both Fuzzy C-means (FCM) and K- Means methods, and these results are shown in Table 1. Fig.5 shows the graph of the comparison of the manual and proposed geometric feature values of Boron TEM nanoparticle images.

Among the extracted nanoparticles of images; A,B, and C,the image A nanoparticle showsa colossal difference between the manual size and the computed size. Hence, considering the applicationsand chemical experts' opinions the enlarged nanoparticle has been ignored. Fig. 3 shows the nanoparticles which are in the range of 0-100μmextracted from Boron TEM images using FCM and K-Means segmentation techniques.The computed results of FCM and K- Means clustering techniques are shown in Table.3.

Table 1: Manual and proposed geometric feature values of Boron TEM nanoparticle images of Fig. 3 and Fig.4

Image	Area(μm)		
	Manual (μm)	Proposed (μm)	
		FCM(μm)	K-Means(μm)
A	0.0163	0.0163	0.0163
B	0.0212	0.0212	0.0212
	0.0350	0.0653	0.0318
	0.0191	0.0226	0.0234
C	0.0412	0.0412	0.0412
	0.0109	0.0099	0.0101
	0.0462	0.0479	0.0470

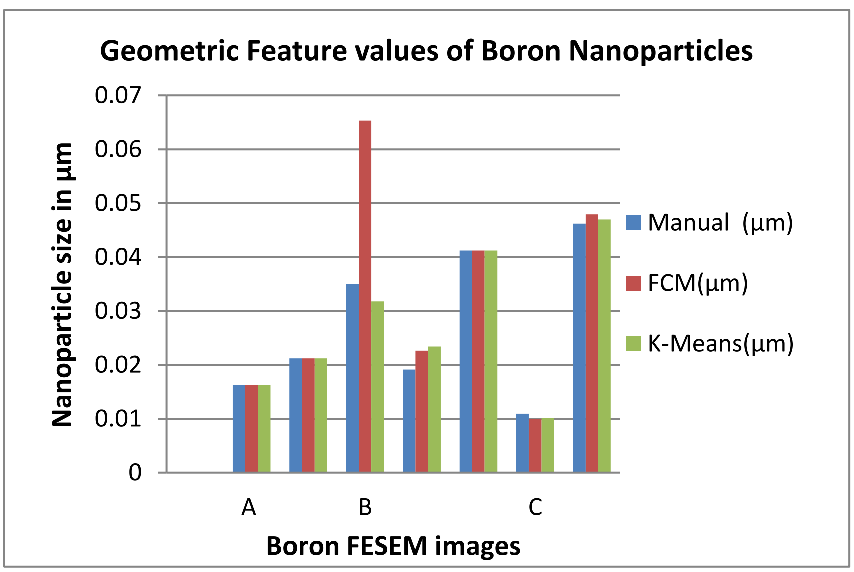

Fig. 5: Manual and proposed geometric feature values of Boron TEM nanoparticle images

Table 2: Area-wise number of nanoparticles using Fuzzy C-Means and K-Means for images A, B, and C.

Images	Area(0µm -100µm) using FCM	Area(0µm -100µm) using K-Means
A	49	13
B	173	67
C	03	03

Based on the experimentation it is observed that the geometrical feature value;the area(size) is calculated using both segmentation techniques and describes some variation in comparison with the manual values, the K-Means segmentation technique is having a 5.87% error compared with Fuzzy C-Means segmentation technique which is 16.78% error, which is shown in Table 3.

Table 3: Details of Error % between FCM and K-means for images Boron TEM images A, B, and C.

Image	Manual	FCM	FCMError (%)	K-Means	K-meansError (%)
A	0.0163	0.0163	0	0.0163	0
B	0.0212	0.0212	0	0.0212	0
	0.035	0.0653	86.67	0.0318	9.19
	0.0191	0.0226	18.32	0.0234	22.51
C	0.0412	0.0412	0	0.0412	0
	0.0109	0.0099	8.83	0.0101	7.69
	0.0462	0.0479	3.67	0.047	1.73
Average Error (%)			**16.78**		**5.87**

Statistical test of Significance: To test the agreement between manual results and algorithm results, the Chi-Square test (at 5% of significance level) is implemented. The test validated that there is a close agreement between manual results and algorithm results. Following are the two hypotheses set for the testing purpose:

Null hypothesis h_0=There is a close relationship between the manual value results and the K-means clustering algorithm,

Alternate hypothesis h_1= There is no relationship between the manual value results and the K-means clustering algorithm.

The formula for the Chi-square test is:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Where X_2:Chi-Squared
O_i:observed values
E_i:expected values

After carrying out the Chi-square test it is observed that the tabulated value is 5.348 and the calculated value is 0.0003215. As the tabulated value is found to be greater than the calculated value, the null hypothesis is proved.

4. Conclusion

In this study the objective is to determine the measurement of the size of Boron nanoparticles by extracting geometrical features using various segmentation techniques viz; Fuzzy C-Means and K-Means. The categorization is based on the standard size of nanoparticles. This standard size of Boron nanoparticles is further used in divergent applications such as;neuron capture therapy of cancer cells, food nutrients, food preservatives, etc. The statistical test of significance is applied using the Chi-square testing method (at 5% of significance level) to check the relationship between the manual results and the algorithm results.The average error for the characteristics of the segmented nanoparticles using Fuzzy C-Means is 16.78% and the same using K-Means is 5.87%. Since the least average error is considered the most appropriate method, it is concluded that the K-Means segmentation method is suitable for segmenting the Boron TEM nanoparticle images. The proposed study also establishes collaborative research work between Chemistry and Computer Science departments to develop computational research on these platforms. Implementing the same algorithm with other nanoparticles images will be considered as our future work.

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