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# Defect Detection of Coatings on Metal Surfaces Based on K-Means Clustering Algorithm

**Yasir Aslam, Santhi N, Ramasamy N, K. Ramar**

***Abstract*****:** ***Defect detection is an important phase for the analysis of the surface quality of products as it influences the subsequent process. The existence of surface defects will affect the corrosion and wear resistance of the end product. The insufficient detection and classification rates of the standard algorithms are infeasible to accomplish the production requirements. Surface defect detection in coated metals with non-destructive techniques is an essential prerequisite for quality analysis in manufacturing stage. The existence of surface defects can significantly alter the deterioration resistance and instinctive qualities of a material and as a result more expansive analysis is essential. This paper proposes a competent and exact approach using K-means algorithm for the detection of surface coating defects. K-means is an unsupervised algorithm used for segmenting the area of interest from background. The proposed method uses a sequence of image processing algorithms to examine and validate the input image real-time accuracy for detection of defects. The proposed method efficiency is featured with test samples and results from experimental analysis. It shows that the proposed method be able to adequately and instinctively recognize the presence of defects inside coatings on metal surfaces.***

***Keywords*** **:** ***Coated surface, Image segmentation, K-means clustering, Surface defect.***

## I. INTRODUCTION

Surface defects are the primary factor influencing the quality of products and as a result accurate defect detection becomes a main issue in industrial applications [1]. In manufacturing for materials comprising textured or non-textured surfaces, inspection of the surface defects is a significant constituent of quality control. In general, the surface defect detection task is grouped as qualitative inspection [2] which requires determining the non-quantifiable even so visually imperfect objects such as crack, stain and wear. With the automatic visual inspection, the defective and non-defective regions of an image consists of non-stationary intensity changes because of the non-uniform texture pattern. In the manufacturing process presence of defects are usually unpredictable and undefined [3]. Defect inspection based upon the manual approaches are time consuming, labor intensive and subject to uncertain error and hence not able to produce accurate results by reason of incompatible standards utilized by individual inspectors.

Therefore, it is essential to develop an automatic surface defect detection system for manufacturing sector.

The modern technology in imaging and image processing, might be deliberated and discovered via machine rather than human. Presently, numerous researchers contribute in expanse of detecting defects. The image thresholding [4] involves the method of extracting each individual image objects from its background. It's a very common defect segmentation process in image processing and it has been studied by many vision experts extensively. Researchers work often on specific domains meanwhile an optimal solution is fetched for every environment. Usually, the problems arise in cases of large variances or small sized object among the background and object intensities. Moreover, it becomes even worse if there is a large amount of noise in the image. For these reasons, there have been developed the methods of local or adaptive thresholding [5], multilevel thresholding methods and so on.

Adaptive thresholding is an image segmentation method which is insusceptible to uncertain lighting conditions. In this, the threshold value is chosen formerly, the foreground and background image components be possibly distinguished through the comparison of pixel values with the selected value of threshold. The Otsu's [6] and median based Otsu's (MBOT) method [7] for surface defect detection is feasibly the best known and most extensively used non parametric and unsupervised thresholding method based image segmentation, however expensive computationally, because the method employed an extensive search for optimal thresholds. In recent past, a lot of multi-objective optimization algorithms are projected on the basis of evolutionary computing to find the optimal threshold. Among the available optimization techniques, Particle Swarm Optimization, is combined with adaptive thresholding (ATPSO) [8] for image segmentation based defect detection. Among several techniques of segmentation, the most commonly used are clustering and thresholding. In clustering methodology [9], the image pixels were aggregated in accordance with the intensities depending upon the number of clusters defined previously. For image segmentation, Fuzzy c-means [10] method is among the most prevalent methods of fuzzy clustering.

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* Correspondence Author
**Yasir Aslam***, Research Scholar, Department of Electronics and Communication Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, India. E-mail: yasiaslam@gmail.com
**Santhi N**, Associate Professor, Department of Electronics and Communication Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, India.
**Ramasamy N**, Associate Professor, Department of Mechanical Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, India.
**K. Ramar**, Professor & Dean, in Computing Science, Muthayammal Engineering College (autonomous), Rasipuram, India.

The traditional Fuzzy c-means (FCM) functions adequately on numerous noise-free images, but is comparatively sensitive to noise owing to unfamiliarity of spatial image information.

K-Means clustering [11] makes an explicit number of disjoint, non-hierarchical clusters suitable for producing globular clusters. It is an unsupervised, numerical, iterative and non-deterministic method. The past researches has shown that it is better employing dimensionality reduction approaches prior to clustering then utilizing k-means which is low dimensional clustering algorithm, instead of high dimension clustering. The procedure utilizes uncomplicated, reasonable elementary projection upholds several data properties including cluster distances, which makes finding clusters easily. Hence, for low dimensional data require exceptional fast clustering algorithms. Here proposed a modified k-means clustering method for detecting metal surface coating defects that could able to identify multiple thin defects of unreliable shapes and sizes with better detection rate.

## II. PROPOSED METHOD

The proposed algorithm involves three main steps: preprocessing, K-Means clustering and post processing by morphological operations, it is shown in fig.1. For segmentation, the images used mainly contain low contrast; hence contrast stretching method adapted for better image eminence. In preprocessing phase, the enhancement in contrast of the test image along with extraction of the periodic pattern as used in classifying defects. In k-means defect categorization, the image is segmented into regions by equal size for pre-detecting periodic pattern. Next, for each block median, the square difference between along with the mean of all block medians were estimated and the information is expedited towards K-means clustering for analyzing defected blocks having advanced discrepancy. The quality of the output image is further improved with post processing by morphological operations.

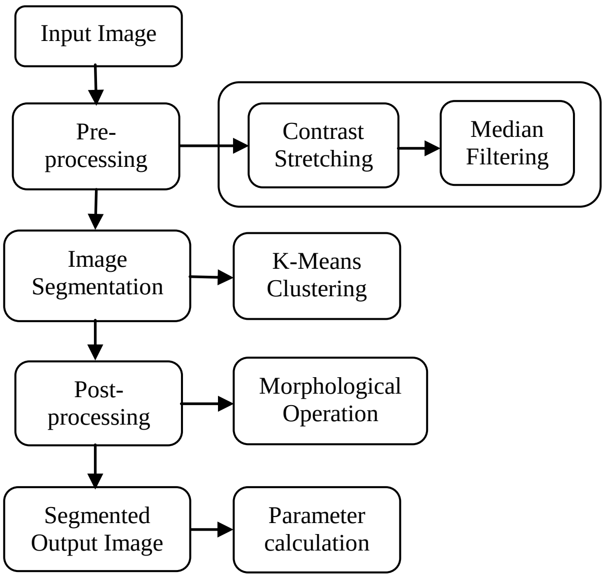


**Fig.1 Process of image segmentation using the proposed method.**

### A. Pre-processing

Generally, the images obtained could deteriorate as of reduced contrast that could result in unreliable detection. The image contrast should be improved to curtail these adverse effects. In image processing, initial process is pre-processing procedure [12] for improving the quality of image. The key intend about preprocessing is redundant noise discarding as well as enhance intensity or strength of image. The contrast enhancement methods [13], inhabits primitive, most elementary since it elevates the contrast involving texture background and defects along with emphasize defects. Subsequently, contrast enhancement procedure such as contrast stretching used to accumulate image contrast and image quality utilizing stretching process. The lower threshold pixel range value and upper threshold value accessed through mapping with range of new pixel through applying this technique and extended directly headed for extensive pixels range in new subordinate stretching value furthermore, surplus pixels would undergo distortion. The median filter [14] often used to remove noise from an image and improve the results of later processing.

### B. K-Means Clustering

In K-means clustering, the test image regions could be clustered as defective or not, image be partitioned over similar size regions as periodic pattern and calculated the each block median value. The non-defective regions indicate definite median values whereas the defective blocks indicate the ranged median values. The median values in K-means clustering [15] incorporated within separate group also affirmed as blocks defective. In support of further accurate sequels, mean of the entire median values (N) computed in accordance with eq.(1), square difference, Diff (z) among block median of each and mean (N) computed in relation to eq.(2).

$$N = \frac{1}{k}\sum_{m=1}^{k} median(z) \qquad z = 1{:}k \qquad (1)$$

$$Diff(z) = (median(z) - N) \qquad z = 1{:}k \qquad (2)$$

where, N-the number of test image blocks, difference values from the blocks defected be apart on or after difference values of available blocks. In K-means clustering [16], these differences are expedited as alternative values of median for categorizing among them. A defect unbound image, in the case of testing unsuitably K-means clustering discloses certain blocks as being defective since the K means clustering organizes blocks between two, by which one is defective. To accomplish this, one more aspect or provision confine analyzing the defective block. The restriction is difference Diff (z) ought to be greater than definite factor and it is incorporated practically the value of constant to be $10^{-3}$.

***The Algorithm***

Algorithm ascertains vector space developed on or after data features, in addition aims to categorize regular clustering within it. The objects are grouped about centroids, $\mu_i \forall_i = 1$, k, determined through objective minimization function as:

$$W = \sum_{i=1}^{k} \sum_{v_j \in C_i} (v_j - \mu_i)^2 \qquad (3)$$

where, $k$-the cluster number that is, $C_i, i = 1,2,\ldots,k$ also $\mu_i$ is the centroid of every one points $v_j \in C_i$.

Here, an iterative version of K-means algorithm is applied wherein algorithm solicits color image being as input [17]. The following is the K-means clustering algorithm steps:

Step 1: Calculate the intensity values assortment.

Step 2: Initialize the centroids utilizing k-indiscriminate intensities.

Step 3: Cluster image points from the centroid intensity values depending upon the distance of intensity values.

$$d^{(i)} := arg\ \min_z \left\| v^{(i)} - \mu_z \right\|^2 \qquad (4)$$

Step 4: Calculate for each one cluster the new centroid.

$$\mu_i := \frac{\sum_{i=1}^{m} l\,(d_{(i)} = z) v^{(i)}}{\sum_{i=1}^{m} l(d_{(i)} = z)} \qquad (5)$$

where, '*m*' indicates number of clusters, '*I*' iterates with intensity values, for each cluster z-iteration with centroids also $\mu_i$-intensities of centroid.

Step 5: Reiterate step 3 and step 4 till there is no change in labels of the cluster to any further extent.

### C. Post-processing

Morphological operations used in the proposed process for detecting the defected areas and these procedures are collateral operations generic on the way to morphological features of image specified. Morphological operations depended on contingent ordering of pixel values as an alternative of numerical values. These operations have been put into practice through the structuring element coordination of any feasible regions in the image furthermore, assessed through correlating pixels in neighboring. The efficiency of method proposed resolved in size along with type of structuring element utilized in morphological operations [18]. The structuring element could potently confining motion for detecting defects. The equivalent sized binary image has been produced in consequence of morphological operation as such erosion and dilation. Each region boundaries have been determined through subtracting the eroded image from original image which is as follows:

$$r = i - (i \ominus t) \qquad (6)$$

where, *r*-image with region boundaries, *i*-binary image also *t* represents structuring element. Correspondingly, binary image dilation represented as $(i \oplus t)$ . Morphological operations dilation and erosion in cooperation exhibit contradictory enacts [19]. These operations conclusions determined via shape as well as size of structuring element. In morphological filtering the distorted regions of a binary image can be removed by means of soliciting the morphological opening operations, wherein erosion ahead of dilation as in opening operation.

$$(i \oplus t) = (i \ominus t) \oplus t \qquad (7)$$

where, *i*-binary image, refers structuring element. The following fig.2 depicts the defects observed from the processed sample input images. The white region represent defects and black region as defect-free surface. The processed two sample input images using the k-means method, adaptive thresholding with Particle swarm optimization (ATPSO), Median-based Otsu's (MBOT) and Otsu method is shown in the figure.

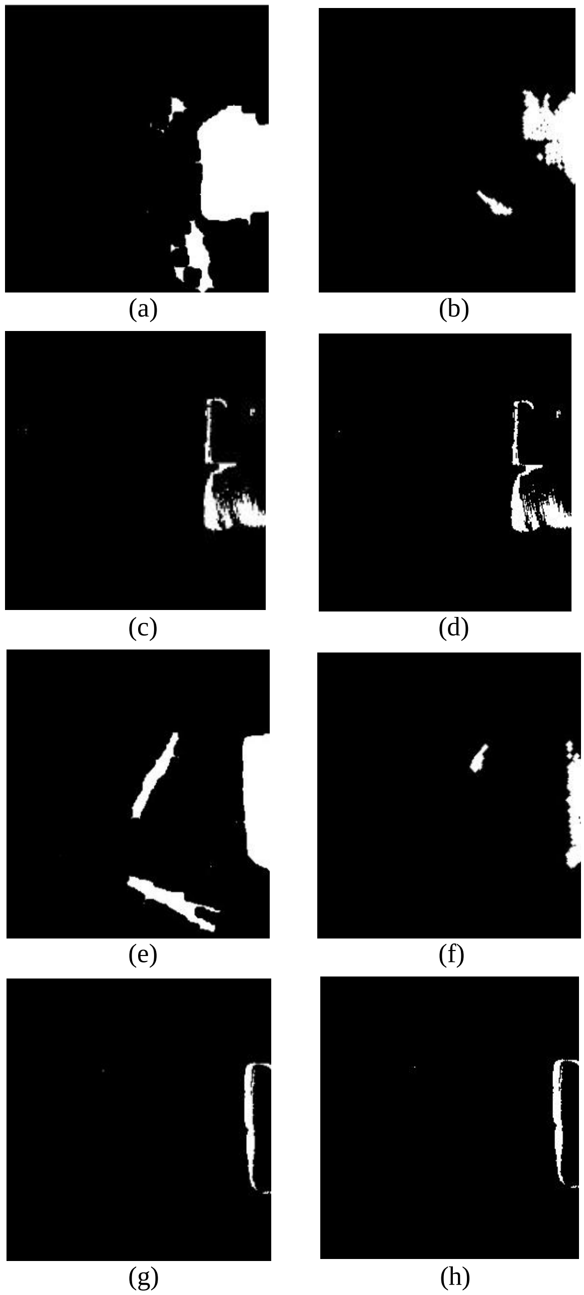


**Fig.2 Represents defect segmentation results from input image sample 1 using the, (a) K-means (b) ATPSO(c) MBOT (d) Otsu and sample 2 with, (e) K-means (f) ATPSO (g) MBOT (h) Otsu.**

## III. EXPERIMENTAL RESULT AND DISCUSSION

Experimental analysis of proposed technique with existing algorithms is represented in the tables below. The above fig.2 shows that the resultant output obtained with the proposed algorithm yields enhanced segmentation effect.

From the table I, II, III and IV, the sensitivity, specificity, accuracy and precision parameters are the statistical measures calculated for each of the methods to represent segmented image characteristics. The resultant values are evaluated and the proposed method found to produce higher quality result. Thus, it is concluded that proposed algorithm results are of high-quality.

### *Parameter Calculation*

For the comparison of different techniques under image processing, certain parameter calculations are carried out. Here, the threshold concepts and k-means clustering algorithms are compared.

(i) Sensitivity: It quantifies consistency of actual positives recognized.

$$\text{Sensitivity} = \frac{TP}{TP + FN} \times 100 \qquad (8)$$

(ii) Specificity: It quantifies consistency of actual negatives recognized and is signified as true negative rate.

$$\text{Specificity} = \frac{TN}{TN + FP} \times 100 \qquad (9)$$

(iii) Accuracy: This is the proximity of a metric value for a standardized value.

$$\text{Accuracy} = \frac{TN + TP}{(TN + TP + FN + FP)} \qquad (10)$$

(iv) Precision: It is statistical inconsistency along with the depiction of random errors criterion.

$$\text{Precision} = \frac{|(\text{relevantmatch}) \cap (\text{derivedmatch})|}{|(\text{relevantmatch})|} \qquad (11)$$

**Table I: Comparison table of different methods in terms of sensitivity criteria.**

| Image No. | K-Means | ATPSO | MBOT | Otsu |
|---|---|---|---|---|
| 1 | 0.8137 | 0.77951 | 0.737642 | 0.70417 |
| 2 | 0.80556 | 0.77461 | 0.739259 | 0.71506 |
| 3 | 0.83074 | 0.7394 | 0.726931 | 0.70475 |
| 4 | 0.80933 | 0.77319 | 0.737271 | 0.72497 |
| 5 | 0.85177 | 0.80573 | 0.755412 | 0.71522 |

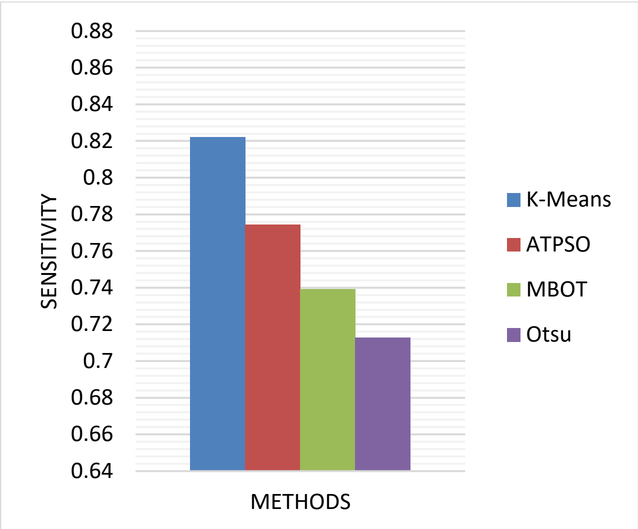


**Fig.3 Comparison graph for sensitivity measurements using different segmentation methods.**

**Table II. Comparison table of different methods in terms of specificity criteria.**

| Image No. | K-Means | ATPSO | MBOT | Otsu |
|---|---|---|---|---|
| 1 | 0.85148 | 0.77326 | 0.71958 | 0.70082 |
| 2 | 0.81973 | 0.76796 | 0.70047 | 0.70239 |
| 3 | 0.83528 | 0.78531 | 0.70016 | 0.70013 |
| 4 | 0.84186 | 0.76642 | 0.70038 | 0.70046 |
| 5 | 0.82987 | 0.80177 | 0.71063 | 0.73762 |

**Table III. Comparison table of different methods in terms of accuracy criteria.**

| Image No. | K-Means | ATPSO | MBOT | Otsu |
|---|---|---|---|---|
| 1 | 0.85648 | 0.80179 | 0.72619 | 0.72699 |
| 2 | 0.83959 | 0.7984 | 0.71677 | 0.71799 |
| 3 | 0.84074 | 0.741 | 0.71657 | 0.71655 |
| 4 | 0.84257 | 0.79742 | 0.72671 | 0.72676 |
| 5 | 0.86118 | 0.81969 | 0.73324 | 0.7501 |

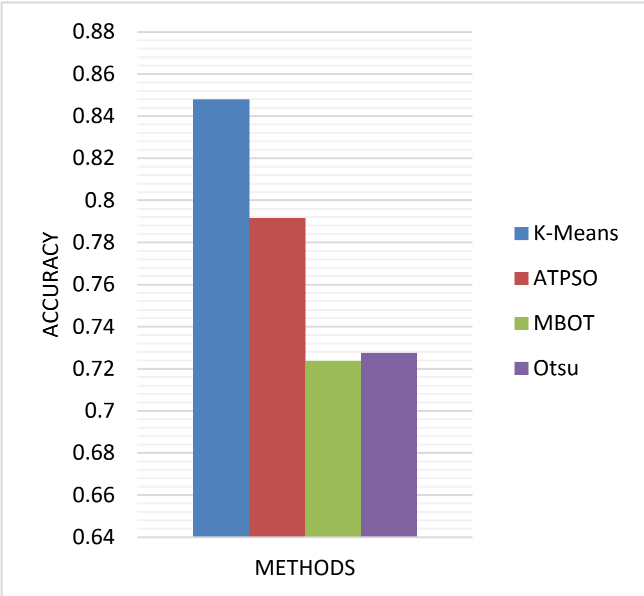


**Fig.4 Comparison graph for accuracy measurements using different segmentation methods.**

**Table IV. Comparison table of different methods in terms of precision criteria.**

| Image No. | K-Means | ATPSO | MBOT | Otsu |
|---|---|---|---|---|
| 1 | 0.86735 | 0.8604 | 0.75221 | 0.75254 |
| 2 | 0.86784 | 0.8289 | 0.75244 | 0.75295 |
| 3 | 0.83541 | 0.83667 | 0.75236 | 0.75235 |
| 4 | 0.8676 | 0.84846 | 0.75242 | 0.75244 |
| 5 | 0.86977 | 0.83824 | 0.75508 | 0.76181 |

The above four tables demonstrate the experimental results of processed input images obtained with the proposed K-Means method and other prevalent approaches such as adaptive thresholding with Particle swarm optimization, Median-based Otsu's method and Otsu's method. In fig.3 and fig.4 represents the graphical comparison of parameters sensitivity and accuracy respectively, found using the four methods.

## IV. CONCLUSION AND FUTURE WORK

The proposed modified K-means method shows good performance as in comparison with other mentioned existing methods. The proposed K-means method provides more accurate estimation of metal surface coating defects, whereas the other methods, ATPSO, MBOT and Otsu fails to locate defects precisely. In comparison among certain alternative segmentation methods, the framework proposed capable to detect surface defect with less divergence. It is well-defined in experimental results that the method implemented includes quite a lot of satisfying attributes and improved segmentation outcome relative to existing procedures. The proposed method is distinct and it takes considerably reduced processing time. But the initial centroids must be selected suitably for further iterations being the constraint involved in this method. In future, this work can be modified by advanced clustering algorithm or convolutional neural network.

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## AUTHORS PROFILE

**Yasir Aslam** received B.E degree in Electronics and Communication Engineering from Anna University, Tirunelveli, Tamil Nadu, India in 2011, and M.E in Communication Systems from Noorul Islam Centre for Higher Education, Tamil Nadu, India in 2013. Currently pursuing PhD degree in the department of Electronics and Communication Engineering (Noorul Islam Centre for Higher Education) in the field of Digital Image Processing.

**Santhi N** received B.E degree in Electronics and Communication Engineering from Madurai Kamaraj University in 1989, M.E in Microwave and Optical Engineering from Madurai Kamaraj University in 1995 and PhD in the area of Image retrieval from Dr.M.G.R.Educational & Research Institute University, in 2013. She has 25 years of teaching experience and is working as Associate Professor in the department of Electronics and Communication Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, India. Her research interest includes Image Processing, Pattern Recognition, Image Retrieval and Soft Computing.

**Ramasamy N** received B.E degree in Mechanical Engineering from Anna University, Chennai in 1984, M.E in Engineering Design from Bharathiar University in 1993 and PhD from Noorul Islam Centre for Higher Education, Kumaracoil in 2016. He has 31 years of teaching experience and is working as Associate Professor, Department of Mechanical Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, India.

**K.Ramar** received B.E degree in Computer Science and Engineering from Govt. College of Engineering.,Tirunelveli in 1986, M.E in Computer Science and Engineering from PSG College of Technology, Coimbatore in 1991 and PhD in the area of image processing from Manonmaniam Sundaranar University, Tirunelveli in 2001. He has 30 years of teaching and research experience. He is working as Professor and Dean in Computing Science, Muthayammal Engineering College (autonomous), Rasipuram, India.