A Survey of Computer Vision Based Corrosion Detection Approaches

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Abstract. There are various destructive as well as non-destructive techniques available to detect corrosion in metallic surfaces. Digital Image Processing is widely being used for the corrosion detection in metallic surface. This non-destructive approach provides cost effective, fast and reasonably accurate results. Several algorithms have been developed by different researchers and research groups for detecting corrosion using digital image processing techniques. Several algorithms related to color, texture, noise, clustering, segmentation, image enhancement, wavelet transformation etc. have been used in different combinations for corrosion detection and analysis. This paper reviews the different image processing techniques and the algorithms developed and used by researchers in various industrial applications.

Keywords: Computer vision · Image processing · Corrosion detection

1 Introduction

We are using metal articles in our daily use, when these materials come in contact with humidity, the chances of corrosion get increased in Iron/steel objects. Corrosion is a chemical process which results in the destruction of metal surface. This results due to chemical and electrochemical reactions because of environmental conditions. As a result, there are loss of metallic components which may further lead to reduced efficiencies in the end use applications of the metal parts. This results in reduced life of metallic parts and hence increases in the maintenance cost. Study of corrosion growth helps in taking preventive measures to avoid such losses.

The introduction of digital image processing opens up expanded real life opportunities to sense in a variety of environments. While physical and chemical tests are highly effective for corrosion detection, however difficult to perform on large surface area. Digital Image processing based approaches are non-destructive approaches and are economical to perform on large areas like ships, metal bridges, electric pole etc.

Digital Image Processing techniques provides fast, reasonably accurate and objectives results. Various image processing techniques like image enhancement, noise removal, line detection, edge detection, registration, wavelet transformation, texture

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detection, morphological functions, color analysis, segmentation, clustering and pattern recognition etc. are base functions that could be combined together to detect corrosion on metal articles.

This paper compares the several image enhancement segmentation, detection and classification techniques that researchers have adopted for corrosion detection. A typical image processing based process for corrosion detection is shown in Fig. 1.

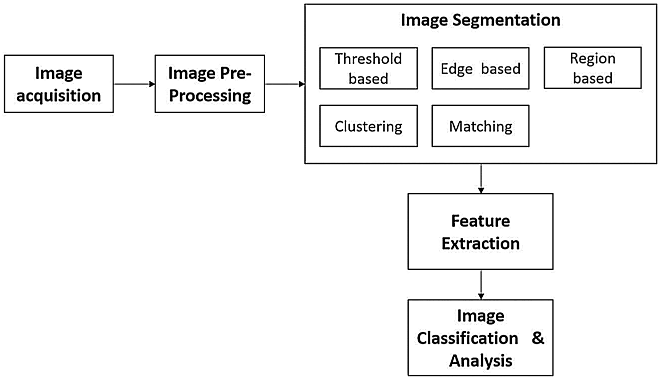

Fig. 1. Corrosion detection process

The typical steps involved in the process are:

1. **Image acquisition:** The first step of image processing is essentially capturing of the images with the help of suitable camera like digital, thermal etc. Images may be captured either manually or automatically. The images thus obtained are processed to study the corrosion. Automated Corrosion Detection System where the images are captured automatically are very fast and efficient as these require minimal manual intervention.
2. **Image Pre-Processing:** The images obtained generally have high background noise and unwanted reflections. To use these images these are required to be pre-processed by different filtering techniques like noise reduction, contrast improvement, image distortion reduction etc. The various Image processing filters can be Median Filter, Morphologic operations, Histogram equalisation, Image stitching, Shadow removal etc.
3. **Image Segmentation:** Once the image is pre-processed, the next step is to divide the image into meaningful structure for image analysis. Image Segmentation techniques uses general image processing methods such as Edge Detection, Region Growing, Thresholding and Clustering. The various categories used for pre-processing are:
   (a) **Threshold based:** In this technique segmentation is done by Histogram thresholding and slicing. It may require a combination of pre and post processing techniques also or may be applied directly.
   (b) **Edge detection:** In this technique, segmentation is done by detecting edges in the image. Once edges are detected, objects in the image are identified based

on these detected edges. In this, first the boundaries are located to locate the object.

(c) **Region based:** In this technique, segmentation is done by starting from the center of the object and then growing the boundaries outward till it reaches the boundaries of the object.

(d) **Clustering:** These techniques are used to explore data analysis of various image patterns. Clustering is basically done by grouping together the patterns which have some similarity.

(e) **Pattern Matching:** In this technique, segmentation is done with the prior knowledge about an object's appearance. These patterns are matched in the image to locate the object.

4. **Feature Extraction:** After segmentation, the next step is the feature extraction. The features are related to color, texture, shape, motion. Few of the feature extraction filters are Haar wavelets, Hough transform, Laplacian of Gaussian (LoG), Histogram of Oriented Gradients (HoG), Gabor filtering, Canny edge detection, Background subtraction and Wavelet transform etc. The images are then processed to identify the corrosion area with series of steps.
5. **Image Classification and Analysis:** In this step, classification is based on certain known features such as size, position, contour measurement, texture measurements etc. Few image processing methods are: Percolation-based models, Graph-based search, Nearest neighbor, Principle Component Analysis, Generalized Hough transform, Line-tracing algorithms, Multi-temporal methods, Support vector machines etc. The image classifiers can be categorized based on Feature, Model and Pattern of the corroded area in the image. This step helps in detecting the corrosion in the images. Once corrosion is detected, the total corrosion area is calculated, to estimate whether the image is partially corroded or fully corroded to take appropriate action.

2 Related Work

Aijazi et al. [1], has proposed a method to form a 3D point cloud based on different positions and viewing angles of several images. The R, G, B values obtained from each image are then converted into HSV zones. This separates out the illumination color component and the image intensity. These parameters help to detect corroded area of different shapes and sizes, within a selected zone. The two methods used for detecting corrosion are based on histogram based distribution and adaptive thresholds respectively. The selection of these two methods is basically dependent on the level of corrosion in the image zone.

Petricca et al. [2], has used Deep Learning approach for automatic metal corrosion detection. He has used a classification based on the number of pixels containing specific red components of the image to implement one version and another deep learning model using Caffe to perform a comparison test.

Ortiz et al. [3] has proposed a solution for detecting corrosion/coating breakdown from the ship/vessel images to support surveyors in ship/vessel inspection. The solution is based on neural network to detects suspected pixels corresponding to defective/

corroded areas. He has used an aerial platform for capturing enhanced images. In this method he has extensively used behavior based high-level controls.

Igoe and Parisi [4] has proposed using smart phone based application to evaluate surface corrosion. In this study corrosion areas were characterized based in red color of iron using a smartphone sensor and java program. R, G, B models corresponding to corrosion were quantified for corrosion analysis. His study finds the 1:1 inverse relationship of red color in the corroded area to the green and blue responses having a quantifiable steeper regression. Errors in the color responses were within 5% range of errors found with the Perlin noise models.

Idris et al. [5] has proposed a vision based corrosion detection method for a pipeline inspection system. By using digital image processing based approach, the analogue signal loss due to the communication interference could be eliminated.

Many researchers have modified the Sobel and Canny edge detector for corrosion detection for pipe line inspection industry. The modified algorithms detected less false edges and also had improved intensity level of edges.

Son et al. [6], has proposed a method consisting of three steps: (1) color space conversion, (2) classification of corrosion area based on J48 decision tree algorithm and (3) determination of blasting area. They have used color space transformation from the Red–Green–Blue (RGB) to the Hue–Saturation–Intensity (HSI) color space and applied pixel level classification to detect the corroded areas. For pixel level classification they have used multiple approaches as Data set, Support-Vector-Machine (SVM), Back-Propagation-Neural-Network (BPNN), Decision tree (J48), Naive-Bayes (NB), Logistic-Regression (LR), K-Nearest-Neighbors (KNN) approaches.

Alkanhal [7], has proposed discrete wavelet packet transform and fractals for extracting Image feature parameters and analysis of pitting corrosion. Using these image processing techniques, he has analysed various characteristics as energy loss, Shannon entropy, fractal dimension and fractal intercept increase parameters with exposure time.

Idris and Jafar [8], has proposed using multiple image filters as Homomorphic, Bayer, Wavelet Denoising, Gaussian, Linear, Anisotropic Diffusion and using neural network to optimize the results. He has used Peak-Signal-to-Noise-Ratio (PSNR) and Mean-Square-Error (MSE) as two error metrics to compare image compression quality.

Corrosion on metal surfaces usually represent as a rough texture and reddish colors, Bonnin et al. [9], has proposed Bayesian framework based classifier and added roughness and color information to it to detect corrosion. He has used Weak-Classifier-color-based-Corrosion-Detector (WCCD) and AdaBoost-based-Corrosion-Detector (ABCD). WCCD is a supervised classifier built around a cascade scheme. This approach uses a chain of different fast classifiers with poor performance to obtain better global performance. He has used classifiers based on Gray-Level-Co-occurrence-Matrix (GLCM), Hue–Saturation–Value (HSV) and bi-dimensional histogram. ABCD method uses Adaptive Boosting paradigm (AdaBoost) for detection as well as classification of corroded areas. The decision trees in this work were based on Classification-and-Regression-Trees (CART) learning technique as weak classifiers.

Ranjan and Gulati [10], has proposed to use basic edge detection filters such as Sobel, Perwitt, Robert and Canny to detect corrosion areas. He then applied dilation and smoothing by eroding the image.

Acosta et al. [11], has proposed texture based classifier to identify corrosion area. He has simulated the corrosion area using Perlin Noise and used Bayesian classifier to identify corroded regions under different texture variations. He has proposed using Re-sampling, Holdout, Leave-one-out, K-fold cross-validation and Bootstrap methods for estimating corrosion area.

Fernndez et al. [12], has proposed image reconstruction approach based on wavelet reconstruction using normalized Shannon entropy calculation for automatic selection of the bands. He has proposed using Shannon Entropy for determination of texture decom-position level on different detail sub-images.

Jahanshahi et al. [13, 26], has evaluated image processing based approaches for corrosion detection for civil infrastructures like bridges, pillars, buildings etc. He eval-uated the effects of several image parameters like block sizes, color channels and color space on the performance of texture analysis based on wavelet texture algorithms. He has observed that a combination of color analysis and texture approached should be used to get better results. He has also concluded multi-resolution wavelet analysis as a more powerful tool for characterization of appropriate features for texture classification.

Daira et al. [14], has proposed using a combination of electrochemical and optical methods for analysing the corrosion processes and their dynamics. He has also done a comparative analysis to study the relation between obtained interferogram and the different polarization curves.

Sreeja et al. [15], has proposed using Gray-Level-Co-Occurrence-Matrix (GLCM) attributes and color attributes based approach to characterize the corroded regions in the image. He has used a Learning Vector Quantization (LVQ) based supervised clustering algorithm to detect corrosion.

Shen et al. [16], has proposed a segmentation approach based on color attribute and texture regions by combining the Fourier transform and image processing. In his research he proposed to adapt various background colors and overcome particular influ-ences for uniformly and non-uniformly illumination regions in corroded regions in the image.

Chen et al. [22], in one of his research has also proposed a combination of color attributes and texture features of images and corrosion detection using Fourier trans-formations. In another research paper he has proposed another approach [17] based on Support-Vector-Machine-based-Rust-Assessment-Approach (SVMRA). In this approach he proposed combination of Fourier Transform and Support Vector Machine (SVM) to provide a method for non-uniformly illumination regions in corroded regions in the image.

Liu et al. [18], has proposed thermal images for corrosion detection and using Prin-cipal-Component-Thermography (PCT). He proposed using Principal-Component-Analysis (PCA) to calculate signal amplitude, phase, principal components and their first and second derivatives for corrosion detection. He has used second principle component to determine depth of corrosion.

Motamedi et al. [19], proposed using CCTV and line laser method to capture images and applying morphological structuring elements. He has proposed using various shapes attributes such as solid line, periodic line, square, rectangle, octagon, diamond, arbitrary, pair and disk etc. to identify corrosion areas.

Ji et al. [20], has proposed using watershed transform applied over the gradient of gray level images.

Ghanta et al. [21], has proposed a corrosion detection method based on wavelet transformation applied to Red–Green–Blue (RGB) color plane of the image and then calculated the energy and entropy values in each sub-band B, (HH, LH, HL, LL) for the texture properties.

Zaidan et al. [23], has proposed a *stdfilt* filter based texture analysis. He also proposed application of structure element, edge detection and image dilation based approaches beside texture analysis for corrosion detection.

Medeiros et al. [24], has proposed color attributes and texture features based integrated approach to describe roughness on the metal surface and color changes because of corrosion. To detect the corrosion regions, he has proposed using Gray-Level-Co-occurrence-Matrix (GLCM) probabilities and Hue–saturation–intensity (HSI) color space statistics from images.

Xie [29], has proposed texture analysis techniques for detecting defects/corrosion on metallic surface. He proposed classification of approaches into four categories as statistical, structural, filter, and model based.

3 Summary and Conclusion

The existing corrosion detection and analysis techniques can be categorized into different categories as:

1. **Wavelet Domain:** This non-iterative approach uses wavelet transformations for calculating corrosion area. The concept is based on component analysis which results in entropy minimization for correction of illumination component of the image.
   The algorithm for detecting the corrosion has three steps as *(1) Feature Vectors Extraction, (2) Training, (3) Detection.* For energy detection and entropy classification feature vectors are used. The Energy and Entropy values are calculated after applying wavelet transform to RGB color planes. Corrosion area in the image can be detected with these extracted feature vectors.
2. **Classification using Support Vector Machine (SVM):** In this technique, classification is based on the color of the corroded area. The degree of the corrosion and the color of corroded area enables to detect the corrosion area.
3. **Damage Analysis based on NDE and SOM:** This technique is based on texture changes using Nondestructive Evaluation (NDE) method. The classification is done based on Self Organizing Mapping (SOM).
4. **Texture Analysis:** With the increase in corrosion the roughness of the metal surface increases. The gray value of the pixels at the edge is different than the gray value outside the boundary. Based on the segmentation detection for texture analysis, corroded and non-corroded parts are differentiated.

Researchers have applied different techniques on different types of images under different environmental conditions. Quality of images may not be good for large surface areas, so noise reduction filters need to be applied for better results. A combination of techniques can be applied on complex shapes to reduce the false positives and better detection rate.

Detection method	References
Color space based detection	[1, 2, 4, 6, 8, 15, 16, 21, 22, 24]
Wavelet transformation based feature vectors extraction, training and detection	[6–8, 12, 13, 21, 26]
Classification using support vector machine (SVM)	[6, 22]
NDE and SOM based analysis	[9, 15, 24, 25]
Texture analysis based detection and analysis	[9, 11–13, 16, 21–24, 29]

4 Future Work

Future work may be pursued to include:

– **Automated collection of Images** - In the current scenario, for the vision based corrosion detection systems the images are not captured automatically, which results in the poor quality of the images due to high back ground noise, image stabilization, poor image illumination etc.
– **Improved algorithms to support complex metal structures** - Most of the algorithms have been developed with the images from simple flat and curved metal surfaces. A lot is required to be researched taking into account complex metal geometries and structures. Future work can also be extended to working on the algorithms which take into account the complex metal geometries which are actually used in many practical scenarios like transportation, bridges, automotive, heavy machines etc.
– **Corrosion Growth Trend Analysis** - Computer vision based corrosion detection methods may also be used for the trend analysis and extrapolating the trends. This will help in taking timely preventive actions to stop the further deterioration of the metallic surfaces.
– **Machine Learning** - When corrosion analysis need to be done on large area, applying the image processing techniques with Machine learning can result in reduction in false positive based on prior history. Machine learning approach can also be applied for performing analysis on corrosion growth rate.

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