Journal of Manufacturing Engineering, June 2024, Vol. 19, Issue. 2, pp 030-036
DOI: https://doi.org/10.37255/jme.v19i2pp030-036

HOMOMORPHIC FILTERING-BASED REFLECTION COMPENSATION AND BINARY THRESHOLDING DURING THE PREPREG-BASED COMPOSITE MANUFACTURING

***Mrinal Sarvagya[1], Ravi Kumar M G[2] and M J Augustin[3]**

[1]School of Electronics and Communication Engineering, REVA University, Rukmani Knowledge Park, Bengaluru, Karnataka-560064, India
[2]Deptartment of Electronics and Communication Engineering, Nagarjuna College of Engineering and Technology, Bengaluru, Karnataka-562110, India
[3]Advanced Composites Division, National Aerospace Laboratories, Bengaluru, Karnataka-562119, India

Abstract

The global aerospace manufacturing industry is witnessing a significant paradigm shift in design and material choice from metals to composites, such as Carbon Fiber Reinforcement Plastics (CFRP) in civil and military aircraft structure design. In prepreg-based composite fabrication, multiple sheets of prepreg material are manually laid in the desired orientation on a mould. The layup process is subjected to 100 per cent ply-by-ply manual visual inspection for detecting inclusion, which can arise when the protective films are missed to get removed or due to the tackiness of the prepregs layers; other materials used in the process get included between layers. Manual inspection during layup is skill-based. The black and reflective nature of the surface makes it difficult to detect the inclusions efficiently. Thus, there exists a need for an automated or semi-automated system that can aid the inspector in detecting and identifying inclusions during fabrication. This paper inculcates the preliminary work towards developing a methodology to determine the inclusions using image processing algorithms. One challenge of using the images is the reflection from the layers. A homomorphic filtering-based approach was developed to reduce the effects of reflection and binary thresholding to detect the inclusion regions. The developed methodology was validated through experimental results. It was found that homomorphic filtering-based reflection compensation and binary thresholding can distinguish the inclusion regions, which can be used by the inspector in the clean room environment.

Keywords: *Homomorphic; Filtering; Reflection; Compensation; Prepreg; Composite*

1. Introduction

Over the last few years, there has been enormous growth in the global aerospace manufacturing industry. In civil and military aircraft structure design, there has been a significant change in design and material choice from metals to composites such as Carbon Fibre Reinforcement Plastics (CFRP). Advanced composite structures demonstrate superior qualities compared to individual materials[1]. The development of lightweight, high-temperature-resistant composite material materialises the next generation of high-performance, economical aircraft designs. Composite materials are light in weight, resistant to fatigue damage, immune to corrosion and high stiffness. These factors significantly reduce the cost of the aircraft in the long run, further improving its efficiency.

A typical composite structure is depicted in Figure 1. Among different manufacturing techniques, the prepreg-based approach is a commonly used method. Prepregs are the building blocks of composite structures, which have pre-impregnated carbon fibre with a resin such as epoxy. The prepreg material has sufficient tack, which enables the layup process. A protective backing film and a paper protect the prepreg material. Prepreg material with the protective film is represented in Figure 2. During the fabrication, the protective films are removed, and the layers are laid one above another as per the design on a mould—non-removal of protective film during layup results in foreign body inclusions in the final structure. Materials like bagging films, tapes, release films, peel ply, etc., are used in the fabrication process for vacuum bagging. A sample layup on a mould is shown in Figure 3.

**Corresponding Author - E- mail: mrinalsarvagya@reva.edu.in*

Journal of Manufacturing Engineering, June 2024, Vol. 19, Issue. 2, pp 030-036
DOI: https://doi.org/10.37255/jme.v19i2pp030-036

Fig. 1 Typical Composite Structure

Fig. 2 Prepreg material

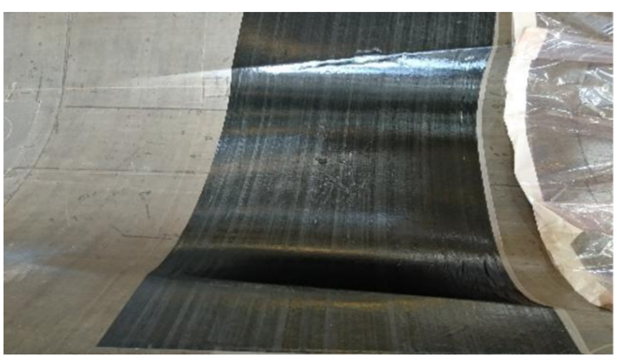

Fig. 3 Prepreg layers on mould

Due to the tackiness of the prepregs, these also can be included between the layers. Once all the composite layers are laid up and cured in an autoclave, the quality of the produced part is assured by a non-destructive evaluation using an ultrasound C-scan. Any inclusions (foreign objects) of 25 mm2 area and above are detected at this stage, and the component will be bound for rejection. Rejection of a fabricated component will be costly considering the material cost, fabrication costs like autoclaves, and workforce. Also, it necessitates the fabrication of a new structure. One way to eliminate this is to detect the inclusions during the layup and remove them. In the present process chain, this is achieved by a clean room inspector through visual inspection. In this method, the inspector closely examines the surface to check the inclusions. The inclusions manifested as thickness variation on the top layer, as shown in Figure 4, and the inspector looks for this change. The reflections from the layers make the detection of inclusions difficult in the cleanroom environment.

Fig. 4 Thickness variation on the top surface due to inclusions

Only some inclusions will be seen from some particular angles. Sometimes, the inspector's boredom or fatigue can also lead to errors. Visual inspection for detecting inclusions is not an efficient method. So, a system and methodology are required to detect and identify inclusions in a composite layup. It will simplify and minimise the time involved in the inspection, making it more efficient and reliable. This paper describes an image processing-based methodology which can aid the visual inspector in detecting the inclusions in the layup process. Photos of the layup from the top surface will be taken and processed to identify any inclusions. A pre-processing methodology was developed and validated experimentally to reduce or eliminate the effect of reflections in the image and determine the inclusion region. The following sections explain the methods developed and their validation on flat laminates.

2. Related Works for Defect Detection

Minimal technologies and methods are available in the open literature to detect inclusions during prepreg-based composite manufacturing. There are few patents published with non-contact Ultrasonic Inspection of CFRP prepregs during lay-up fabrication[2], Multispectral imaging [3], and foreign object video detection and alert system[4]. Ultra-sound-based inspection requires additional set-up and access to both sides of the mould, which is not feasible for all cases. The high reflection from the surface poses challenges in video-based and multispectral-based approaches. A review of methodologies adopted by similar industries was also carried out. For assuring the fabric in the textile industry, an automatic fabric defect detection of un-patterned and patterned fabrics using image processing is proposed in [5]. In this method, the golden template and the Gabor-filtered image are subtracted to obtain the resulting image. The defect was determined by comparing the reference and tested images' periodic and non-periodic histogram equalisation. Quality control and maintaining the rate of production time are essential concerns in the metallic industry. Automatic identification and classification of defects in the surfaces at the early stage of production were presented by [6]. The Gabor filter plays a vital role in creating a Gabor filter bank for the input image from the collection of images of metal plates. Features are extracted when comparing a test image with statistical values, and a unique image is obtained by data fusion. Based on a threshold value, defects such as cracks and holes were classified with bounding. This method is helpful for present applications for the classification of inclusions. MeanAlg and Textile ImagingAlg [7] was used to detect fabric defects. MeanAlg subdivides images acquired in windows of DX x DY pixels and computes mean and pseudo standard deviation. The algorithm extracts a feature from each window, a feature vector f = [M, D]. Based on the mean value and standard deviation, classification based on intensity and contrast features is extracted. Based on this, it is capable of detecting changes. Textile Imaging Alg, labelling the defected region using a threshold value of the grey level of adjacent pixels. A new automatic thresholding algorithm [8], based on the defective region histogram and the selection of its extreme edge as the threshold value, is proposed for segmenting defective objects in the foreground from the image background. A background mask from the mean grey-level values of the entire image was created, and the original image was subtracted with the mask designed to extract the features of the defective region. The histogram was computed to the resultant image to estimate extreme edge value to separate defects from the background. John Huntley Belk [4] proposed a method for detecting foreign objects using a light source, video camera, and colour image processing system. The diffused light source is used to illuminate the surface. The video camera is placed within the field of view of the surface. These video signals are converted to a digital colour image. Images are compared with the predefined images, and new colour images are subtracted from the predefined images to detect foreign objects. If a foreign object is present, the operator is warned to remove foreign objects. An image processing-based algorithm for Improved pavement crack detection was developed[8]. The crack information from the image was extracted using grey level transformation, median filter, and image intensification. It includes the removal of some background noises and the elimination of small noises. This method debilitates loud noises to some range, whereas marginal information of cracks is reserved. A histogram is computed for intensification of the defect region using this method. The convolutional neural network is used to extract the features for the given task automatically, provided that the input can be represented as a tensor in which local elements are correlated with one another. Deep learning Convolutional Neural Networks (CNN) is challenging since it requires many labelled training data to train CNN from scratch. This paper elaborates on the use of fine-tuning CNN for pre-trained images[9]. The convolutional neural network performs better compared to other classic neural networks. The convolutional layers take advantage of the inherent properties of images.

3. Methodology

Homomorphic filtering is a technique used to remove multiplicative noise and correct the image's non-linear illumination. Reflection can be considered as non-linear illumination and, in the present application, acts as a source of noise. Before applying the image processing algorithm to detect inclusions, pre-processing steps must be applied to minimise illumination. Then, binary thresholding is used to detect the inclusion regions. The significant steps in the process are

i. Conversion and selection of Region of Interest (ROI) of an image
ii. Pre-processing of an image using Homomorphic filtering
iii. Algorithms for detection and classification of inclusions.

The algorithms developed are implemented in Mat-lab2018a using an image processing toolbox[10]. The overall process is represented in Figure 5.

DOI: https://doi.org/10.37255/jme.v19i2pp030-036

3.1. Conversion and Region of Interest (ROI) of an image

The captured image is an RGB image. The image is converted to grayscale because it has a pixel value ranging from 0-255, simplifying the algorithm and reducing computational requirements. Some unwanted parts can be captured while capturing an image. The region of Interest (ROI) method was used to select the area that has to be processed. The following techniques adopted are freehand, rectangular box or circle to select the ROI [14]. Fig. 6 shows an original image, a grayscale image, and an ROI-chosen image.

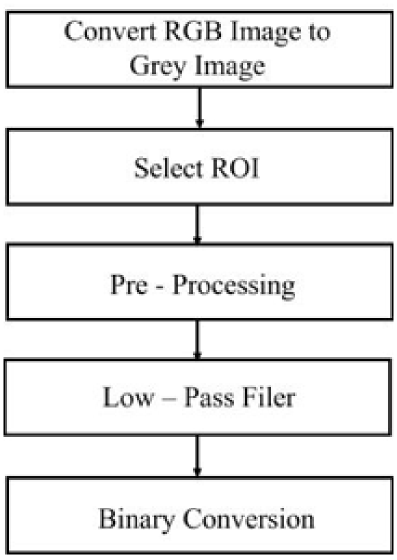

Fig. 5 Flowchart for proposed work (overall process)

3.2. Pre-processing of an Image Using Homomorphic Filtering

According to the illumination-reflectance model, the intensity of a pixel is the product of illumination and reflectance of the objects as given by equation 1.

$$I(x,y)=R(x,y)\cdot L(x,y) \quad (1)$$

I am an image, *L* is scene illumination, and *R* is scene reflectance. Reflectance happens from the scene objects' properties, and Illumination arises from the lighting condition while capturing the image. Typically, illumination variation will be slow compared to reflectance. Reflectance change will be abrupt at object edges. Using these differences, a illumination component is separated from the reflectance part. In homomorphic filtering, logarithmic transformation transforms multiplicative components into additive components. Then, taking log on both sides of equation 1,

$$log(I(x,y))=log(R(x,y)\cdot L(x,y)) \quad (2)$$

A high-pass filter removes the low-frequency illumination components in the log domain while preserving the high-frequency reflectance component. Figure 7 shows the block diagram of the Homomorphic filter.

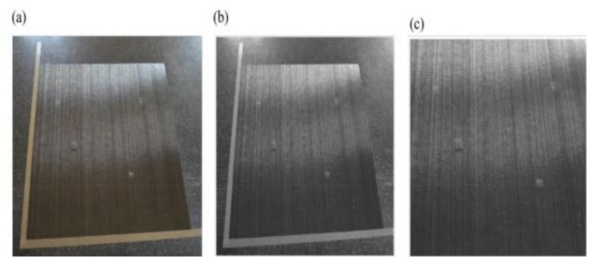

Fig. 6 (a) Original image (b) Greyscale image (c) ROI image

Different types of high-pass filters, such as Gaussian, Butterworth, and Chebyshev filters [15]. Figure 8 shows a homomorphic filter in the frequency domain where the Gaussian filter is used as a high-pass filter. The impact of the homomorphic filter on the original image is presented in Figures 9(a) and 9(b). After getting converted to an ROI image, the Greyscale image acts as an input to the homomorphic filter, which minimises reflection to a greater extent as an output.

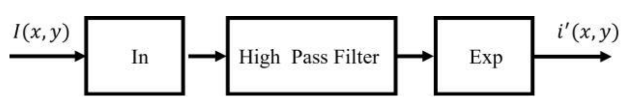

Fig. 7 Homomorphic filter

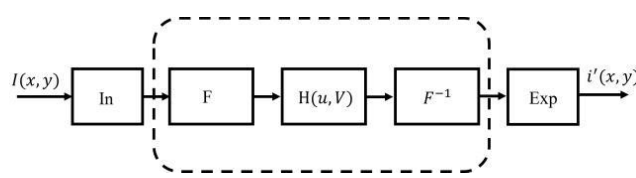

Fig. 8 Infrequency domain

Journal of Manufacturing Engineering, June 2024, Vol. 19, Issue. 2, pp 030-036
DOI: https://doi.org/10.37255/jme.v19i2pp030-036

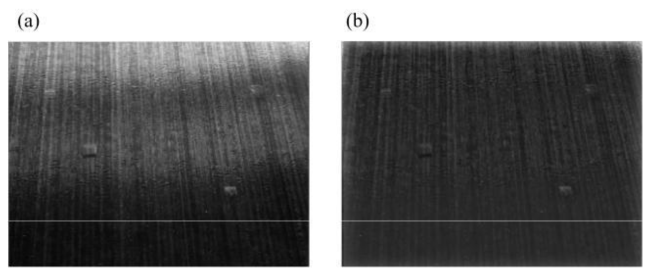

Fig. 9 (a) Grey Scale Image (b) Reflection compensation-image

3.3. Inclusion detection algorithm

The algorithm for inclusion detection includes a low pass filter and binary conversion

3.3.1. Low Pass Filter

A low-pass filter removed the high-frequency component from reflection-compensated images. FFT shift is performed to rearrange uncentered frequencies and to log-transformed images with zero padding. Inverse FFT is performed to obtain an original image with inclusions detected.

3.3.2. Binary Conversion

Low-pass filtered images are converted to binary images by thresholding. The threshold was calculated using the trial and error method and was found to be 0.055 in most cases. Figure 10 shows the inclusion, filtered output, and binary output schematic with and without reflection compensation. The white indicates the inclusion regions in the binary converted Figure 10(d). It can be seen that the reflection compensation leads to better detection of inclusion regions.

4. Results

The abovementioned methodology can be validated through experimental studies on a flat surface layup. On a flat surface, one layer of prepreg has been placed. The layer is de-bulked (to remove the air gaps) by applying a vacuum. The inclusions are placed on top of this layer according to the schematic. The nomenclature of the defects is listed in Table 1. Over and above the defects, another layer has been placed and de-bulked by applying a vacuum. The images are captured using the standard camera with a resolution of 12M (without a zoom lens facility). The above-mentioned homomorphic filtering methodology has been applied to the captured image. Four flat layups are made with inclusions of different types, sizes and shapes. The results are presented in Figures 11 to 14.

In the First trial, Figure 11(d), out of 5 inclusions, three inclusions, such as cloth-based film, BD backup film, and glass prepreg backup film, were visible. The porous and non-pour release film has not been detected.

Table 1 Thickness variation of inclusions

Sl. N	Defects	Thickness (microns)
1	Porous Release Film	25
2	Non-Porous Film	25
3	Cloth Based Film	50
4	Bagging Film	50
5	Flash Breaker	64
6	Paper Based Film	70
7	Adhesive Backed Film	70
8	UD Backup Film	70
9	BD Backup Film	80
10	Tooltec	120
11	Peel Ply (Orange)	130
12	Peel Ply (White)	150
13	Glass Prepreg Backup Film 270	

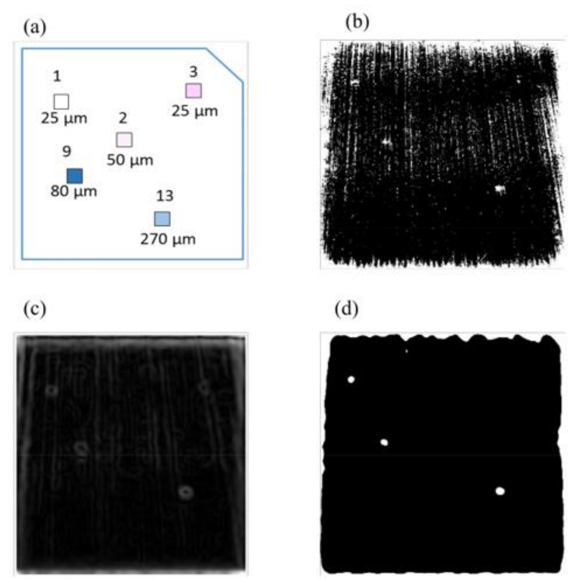

Fig. 10 (a) Schematic of Inclusion (b) Inclusion detection with reflection (c) Low pass filter output image (d) Inclusion detection with reflection compensation

Journal of Manufacturing Engineering, June 2024, Vol. 19, Issue. 2, pp 030-036
DOI: https://doi.org/10.37255/jme.v19i2pp030-036

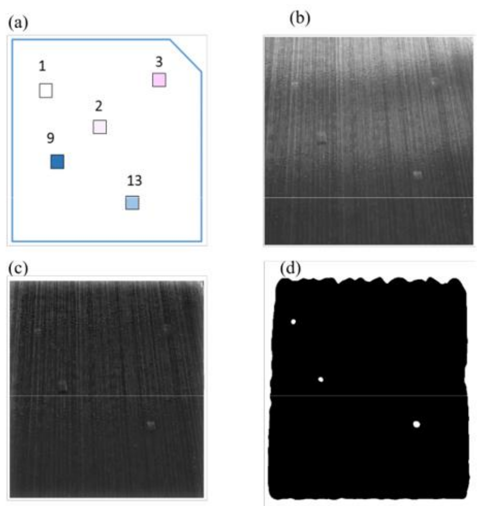

Fig. 11 (a) Schematic of inclusion regions (b) Original Grey Scale Image (c) Reflection Removed Image (d) Inclusion Detected Image

Cloth-based film, flash breaker, and bagging film inclusion are detected in the Second trial Figure 12(d); the white indicates the inclusion regions. Porous and Non-Porous could not be detected due to the porous thickness, which is 25mm thickness. In trial 3, Bagging film, BD backup film, peel ply (white) and porous release file were kept as Inclusions of different shapes, as shown in Figure 13. Bagging film, BD backup film and peel ply (White) were detected, but porous release film could not be revealed. All inclusions, such as UD backup film, BD backup film, and Toltec, were detected in Figure 14(d).

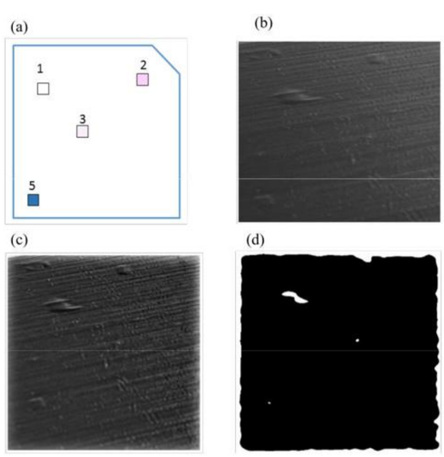

Fig. 12 (a) Schematic of Original Image (b) Original Grey Scale Image (c) Reflection Removed Image (d) Inclusion Detected Image

In all trials, different types of inclusions with different shapes were kept. All inclusions with a thickness of 25 microns and above were detected using this approach.

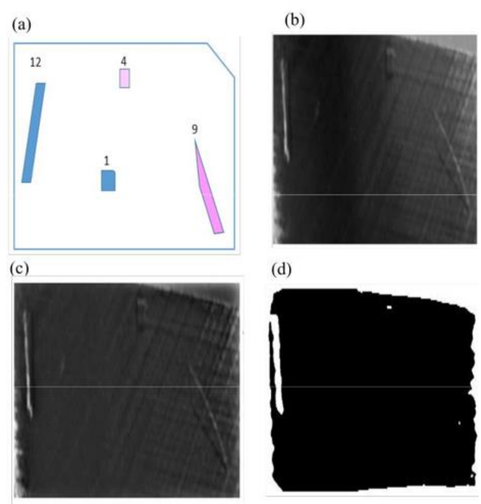

Fig. 13 (a) Schematic of Original Image (b) Original Grey Scale Image (c) Reflection Removed Image (d) Inclusion Detected Image

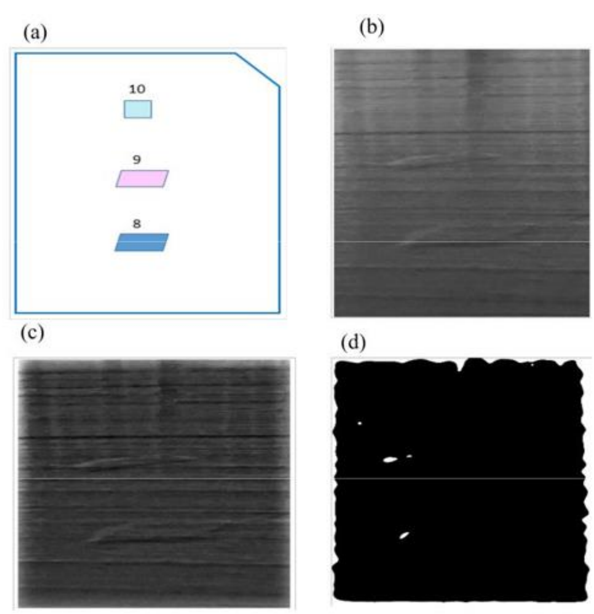

Fig. 14 (a) Schematic of Original Image (b) Original Grey Scale Image (c) Reflection Removed Image (d) Inclusion Detected Image

5. Conclusion

Homomorphic filtering and binary conversion-based approaches have been developed for inclusion detection in prepreg-based composite manufacturing. The developed methods were validated through experimental studies. A homomorphic filtering-based approach is capable of reducing the effects of reflection. It was also found that the reflection compensation made it possible to apply the threshold-based binary conversion to detect the inclusions. Based on this approach, most inclusions are detected except for porous and non-porous release films. Reflection-compensated binary images can be used as a feature of a machine-learning framework for automatic classification or labelling of the inclusion region.

References

1. *S. Rusnáková, D. Kučerka, Š. Husár, R Hrmo, M Kučerková, and V. Rusnák. "Education in composite materials." In 2013 International Conference on Interactive Collaborative Learning (ICL) and the 2013 International Ultrasonics Symposium (IUS), pp. 213-218, 2013.*

2. *M. D. Farinas, T. E. Gómez Álvarez-Arenas, E. Cuevas Aguado, and M. García Merino. "Non-contact ultrasonic inspection of CFRP prepregs for aeronautical applications during lay-up fabrication." In the 2013 IEEE Conference on Eng. Technol. and Human-Machine Systems and Cybernetics (IHMSC), pp. 1590-1593, 2013.*

3. *J. R. Paul G. Vahey, Gregory J. Werner, Robert Arthur Kisch, Paul H. Shelley. "Multispectral imaging system and method for detecting foreign object debris." US Patent US20160146741A1, 2014.*

4. *John Huntley Belk, Michael Tony Gaston. "Foreign object video detection and alert system and method." US Patent US6064429A, 1998.*

5. *Jun-Feng Jing, Shan Chen, and Peng-Fei Li. "Fabric defect detection based on golden image subtraction." Coloration Technology, vol. 133, no. 1, pp. 26-39, 2017.*

6. *Chaitali Tikhe and J. S. Chitode. "Metal surface inspection for defect detection and classification using Gabor filter." Int. J. Innov. Res. Sci., vol. 3, no. 6, pp. 13702-13709, 2014.*

7. *Antonio Baldassarre, Maurizio De Lucia, Paolo Nesi, Francesca Rossi, and Jacopo Zamberlan. "Real-time defect detection on cloths." In Optical Measurement Systems for Industrial Inspection, vol. 3824, pp. 353-364. SPIE, 1999.*

8. *Zhu Qingbo. "Pavement crack detection algorithm based on image processing analysis." In 2016 8th International Conference on Intelligent Eng. and Tech., vol. 1, pp. 15-18. IEEE, 2016.*

9. *Nima Tajbakhsh, Jae Y. Shin, Suryakanth R. Gurudu, R. Todd Hurst, Christopher B. Kendall, Michael B. Gotway, and Jianming Liang. "Convolutional neural networks for medical image analysis: Full training or fine-tuning?" IEEE Transactions on Medical Imaging, vol. 35, no. 5, pp. 1299-1312, 2016.*

10. *MathWorks. "Image processing toolbox." 2022.*