Cracks Detection using Artificial Intelligence to Enhance Inspection Efficiency and Analyze the Critical Defects

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Abstract –

Cracks are one of the significant criteria utilized for diagnosing the disintegration of solid structures. Normally, a structural designer with specific information would assess such structures by checking for breaks outwardly, outlining the aftereffects of the examination, and afterward getting ready to investigate information based on their discoveries. A review technique like this is not without a doubt, as it requires manual chronicle of upwards of a few hundred thousand splits individually. However, it additionally cannot precisely identify the length and state of the breaks. To handle the issue, the industry has progressively looked toward utilizing AI detection to conduct a direct based assessment. Researchers are as of now building up a mobile-based intelligence equipped with AI analytics for recognizing splits and different imperfections, which will upgrade the proficiency of the investigation process and enhance the emergency response towards users. This study aims to provide an insight on the most efficient crack detection method by comparing several techniques. It was found out that the hybrid technique was the most efficient method to detect cracks. This technique combines the positive points from both the artificial neural network (ANN) and artificial bee colony (ABC) to come up with a more proper entirely new method.

Keywords –
Cracks Detection; Inspection Enhancements; AI Detection; Cracks Deep Learning; Buildings Defects

1 Introduction

Structural systems in civil engineering are exposed to deterioration and damage during their service life. Damage is defined as a weakening of the structure which may cause undesirable displacements, stresses, or vibrations to the structure leading to sudden and catastrophic consequences. Damage that severely affects the safety and functionality of the structure and detection of it at an early stage can increase safety and extend its serviceability. Thus detection of damage is one of the most important factors in maintaining the integrity and safety of structures.

Visual inspections have always been the most common approaches used in detecting damage on a structure. However, these inspection techniques are often inadequate for assessing the health state of a structure especially when the damage is invisible to the human eyes. Thus, in many situations to ensure structural integrity, it is desirable to monitor the structural behavior when damage is not observable. Some numerical techniques such as the finite element method, artificial neural networks, genetic algorithm, and fuzzy logic have been applied increasingly for damage detection with varied success [1].

In recent decades there has been an increasing interest in using neural networks to predict and estimate the damage in structures. ANNs can be considered as an Artificial Intelligence (AI) technique and the structure of an ANN bears a very approximate similarity to the human brain. ANNs are employed when the relationship between the input and output is complicated or when the application of another available technique requires long computational time and the effort is very expensive [2].

ANNs are a powerful tool used to solve many real-life problems. They can learn from their experience to improve their performance and to adjust themselves to changes in the environment.

Damage detection as an inverse problem can be identified using ANNs from the measured responses under the excitation of the structure. The inverse problem is defined as the determination of the internal structure of a physical system from the system's measured behavior or identification of the unknown input that gives rise to a measured output signal. The neural network can be trained to recognize the characteristics of an undamaged structure as well as those of the structure with elements of varying degrees of damage. The trained neural network will then have the ability to identify the location and the extent of damage of individual elements [3].

There are four levels of damage identification consisting of determination of the presence of damage in the structure, determination of damage location, and determination of the severity of damage [4]. The fourth level that is the prediction of the remaining service life of the structure is associated with fatigue life and fracture mechanics and will not be addressed in this review. In this paper, a review of the literature for damage identification and structural health monitoring based on measured dynamic properties by using ANNs during the last two decades is presented.

While there are a number of literature that discuss about crack detection methods, none of them provides a direct comparison between the methods to find out the one that has the best efficiency and accuracy rate. This is an important point that needs to be resolved as it may help designers to come up with the most efficient design from the very beginning to anticipate cracks on different surfaces. This is why this study aims to close this gap as a contribution to the field of research with the purpose to provide an insight for future researches, particularly within the crack detection discourse.

2 Literature Review

2.1 Cracks Development

Different types of engineering structures, including concrete surfaces, can have fatigue stress which can lead to creating cracks. This results in a reduction of local stiffness and can also result in material discontinuities. If such measures can be detected in an early manner, then proper actions can be taken to prevent any sort of damage and failure. Cracks on the concrete surface are one of the indications where users will be able to see the degradation of the overall structure. Manual inspection is often used for inspecting the crack properly [5].

In such a method, the sketch is prepared manually, and any sort of conditions related to irregularities are kept in record. However, there are shortcomings of using such a manual approach since this can be subjected to the knowledge and experience of the specialist who is investigating the case. To tackle the issue, the Artificial Intelligence-based system gets more popular now.

This is an objective-based practical solution. Using Artificial Intelligence, it is possible to identify the crack specifically. Such actions have prompted the creation of Cracks deep learning.

2.2 Cracks Detection through Artificial Intelligence

When the solid structures disintegrate, then there is a case of developing cracks. The structural designer is the person responsible for providing such information that will look for cracks.

The Artificial Intelligence or AI system is improving regularly. With its regular evolution process, the system is used on different cracks detection process. Some systems are used to find structural damage that can exist in major infrastructure, including- dams, skyscrapers, nuclear reactors, bridges, and other buildings defects.

This technique focuses on using video technology and examines it frame by frame to look for any sort of cracks. Artificial Intelligence (AI) is mainly used to track the cracks from one frame to another. A specific operator remains who reviews the specific frames of the video to find the cracks and understand what actions are needed.

AI detection technology helps to reduce any accidents or deaths. It focuses on the computer doing the hard work and gives the human operator specific information related to the cracks [6].

2.3 Cracks Detection Process

It has been known that if there is any tiny crack in the nuclear reactor or any other infrastructure, then it could lead to catastrophic consequences.

There could be cataclysmic consequences in high risk and sensitive areas, such as- nuclear reactors if there is unidentified or under-identified structural damage. The use of Artificial Intelligence helps to create an automatic crack detection system to find out cracks properly and not to misidentify the small scratches.

Therefore, the technicians are required to review the videos frame by frame basis. The process itself is time-consuming and there could be human errors as well [7].

It can be considered a tedious task to inspect any cracks manually. It is both complex and very time-consuming. In some cases, such actions can also pose a greater danger. Therefore, authorities are now moving towards AI detection that will help them to look for buildings' defects or cracks detection.

In such cases, there has also been the use of drones that look fly around the structures, capture the live feed to the AI algorithm so that it can find the right images and also classify them into cracks or non-cracks region [8].

In terms of deep learning, one of the challenging things is network training. There are several parameters involved in this and it also requires a huge level of data for training purposes. Some techniques are considered to be efficient whereas some others are not. There is a technique known as per-pixel window-sliding which can be used for crack detection. This process is considered extremely inefficient and could also contribute to a much higher level of cost. However, there is an alternative to using the per-pixel window-sliding where users will be able to utilize the Convolutional Neural Network or CNN for pre-selection purposes that will help to divide the full-size image into few image blocks. Inspection enhancements procedures are also used to properly understand cracks detection. To process the cracks accurately, there have been propositions to use CNN for block-level crack detection [9].

2.4 Cracks Classifications

Cracks classification is considered to be an approach through which specific crack type can be found using machine learning algorithms. Crack detection normally identifies or looks towards the presence of a crack. On the other hand, cracks classification deals with the crack classification based on feature which has been extracted from the crack region [10]. It is essential to understand the type of cracking that has been identified. Therefore, the classification of such cracks is needed to be understood. After detecting the crack in the pre-processing phase, the next step involves the detection and classification of the type of cracks in the overall processing phase. The right kind of classification model is therefore important in such cases. These cracks can be classified into seven different categories as in the following- Alligator cracking, hair cracking, multi cracking, diagonal cracking, block cracking, longitudinal cracking, and transverse cracking [11].

2.5 Shapes of Crack

The form and size of the crack can sometimes indicate the underlying problem. Cracking can be horizontal, vertical, stepped, cogged, or a combination of all these. When assessing cracks, the width of the crack is often more important than the length of the crack.

Stepped cracks tend to follow the lines of horizontal and vertical joints in buildings, such as beds of mortar between bricks or blocks and may indicate structural movement.

Vertical cracks may indicate that structural components such as bricks or blocks have failed and so can be a sign of significant stresses within the building structure.

Table 1. Damage to Walls caused by the movement of Slabs and Footings, and other Causes [10]

Application	Data Analytics
< 0.1 mm	Hairline cracks
< 1 mm	Fine cracks that do not need repair
< 5 mm	Cracks noticeable but easily filled. Doors and windows stick slightly.
5 mm to 15 mm (or a number of cracks 3 mm or more in one group)	Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weather tightness often impaired.
15 mm to 25 mm but also depends on number of cracks	Extensive repair work involving breaking-out and replacing sections but also depends on walls, especially over doors and windows. Window and door frames distort. Walls lean or bulge noticeably, some loss of bearing

Cracks that are wider at the top or the bottom may indicate that there has been foundation movement, with the direction of the widening indicating the likely direction of the movement.

Horizontal cracks may indicate that an element such as a wall is failing, and this may present a safety concern.

3 Research Methodology

3.1 Study Using ML

In this work, the authors develop an ML algorithmic framework for failure detection and classification merging a pattern recognition (PR) scheme and ML algorithms applied to a damage and fatigue phase-field model. The authors consider an isothermal, linear elastic, and isotropic material under the hypothesis of small deformations and brittle fracture.

We simulate the phase-field model using Finite Element Method (FEM) and a semi-implicit time-integration scheme to generate time-series data of damage phase-field ϕ and degradation function

$$g(\emptyset)=(1-\emptyset)2$$

From virtual sensing nodes positioned at different locations across a test specimen. The authors introduce a PR scheme as part of the ML framework, in which time-series data from FEM node responses are considered as a pattern with a corresponding label. The authors define multiple labels for "no failure", "onset of failure" and "failure" of the test specimen based on tensile test load-displacement curve and damage threshold concept. Once the patterns representing different states of the material are identified, the proposed ML framework employs k-nearest neighbor (k-NN) and ANN algorithms to detect the presence and location of failure using such patterns. In this study, the authors consider different failure types to further assess the performance of the framework. Also, by introducing noise to the time series data, the authors ascertain the robustness of the proposed framework with noise-polluted data, leading to the effective use in failure analysis under high sensitive/uncertain parameters and operators. The findings from this study will pave a way for the development of novel data-driven failure prediction frameworks, which can efficiently establish a link among the classification results (i.e., accuracy) and different phase-field model parameters, thus enabling the computational framework to identify those parameters affecting model's accuracy and updating them to achieve the best performance.

3.2 Cracks Modes

Various studies over the last decade have indicated that a beam with a breathing crack, i.e., one which opens and closes during oscillation, shows nonlinear dynamic behavior because of the variation in the structural stiffness which occurs during the response cycle. On the other hand, the effect of moving loads and masses on structures and machines is an important problem both in the field of transportation and in the design of machining processes. A moving load (or moving mass) produces larger deflections and higher stresses than does an equivalent load applied statically.

These deflections and stresses are functions of both time and speed of the moving loads. It is, therefore, essential to detect and control damages in structures subjected to a moving mass. Very few studies have been reported in the literature that deals with moving load or moving mass problems under the effect of cracks.

Diagnosing a cracked component by examining the vibration signals is the most commonly used method for detecting this fault. The fault detection is possible by comparing the signals of a machine running in normal and faulty conditions.

Depending on the crack's size and location, the stiffness of the structure is reduced and, therefore, so are its natural frequencies compared to the original crack-free structure. This shift in natural frequencies has been commonly used to investigate the crack's location and size.

Vibration analysis can also be carried out using Fourier transform techniques like Fourier series expansion (FSE), Fourier integral transform (FIT), and discrete Fourier transform (DFT). Identification and diagnosis of a crack in inaccessible machine members have gained importance in now a day using vibrational analysis and artificial intelligence technologies. Using a modern technology sensor is placed near the inaccessible internal machine component. The piezoelectric transducer of the sensor produces a vibrational signal which is transformed using Wavelet Transformation technology.

These signals are time and frequency-dependent. After extracting fault features, a proper artificial neural network is implemented for aiding of the fault classification. An intelligent fault diagnosis system is performed throughout combing the approach to fault diagnosis with an artificial neural network. An artificial neural network is proved as a reliable technique to diagnose the condition of a rotating member. In general, the cracks present in the beams are not always open or close condition. It always varies from time to time depending upon the situation. If the loads are static like load due to dead weight, the load of the beam, etc. and if the deflection is more than the vibration amplitude then the crack becomes an open crack, otherwise it will be breathing crack.

Beams are one of the most commonly used structural elements in several engineering applications and experience a wide variety of static and dynamic loads. Cracks may develop in beam-like structures due to such loads. Considering the crack as a significant form of such damage, its modeling is an important step in studying the behavior of damaged structures.

Knowing the effect of crack on stiffness, the beam or shaft can be modeled using either Euler-Bernoulli or Timoshenko beam theories. The beam boundary conditions are used along with the crack compatibility relations to derive the characteristic equation relating to the natural frequency, the crack depth, and location with the other beam properties.

4 Results & Evaluation

The form and size of the crack can sometimes indicate the underlying problem. Cracking can be horizontal, vertical, stepped, cogged, or a combination of all these. When assessing cracks, the width of the crack is often more important than the length of the crack.

The accuracy of the classifications was evaluated through an analysis of the confusion matrices, this being the most commonly used method to validate this type of model. This matrix contains information based on the percentages of observed and estimated data for each object is classified, in which different parameter that indicates the precision of the classification can be calculated [14]. The parameters that arise from the error matrix and the formula to calculate them are as follow:

Precision $$P = \frac{\sum_{i=1}^{m} x_{ii}}{N}$$

Accuracy $$P_A = \frac{x_{ii}}{x_{\sum i}}$$

Precision $$U_p = \frac{x_{ii}}{x_{i\sum}}$$

Coefficient Analysis

$$K = \frac{N \sum_{i=1}^{m} x_{ii} - \sum_{i=1}^{m} x_{i\sum}\ x_{\sum i}}{N^2 - \sum_{i=1}^{m} x_{i\sum}\ x_{\sum i}}$$

Where m = Total number of classes, N = Total number of pixels in the m reference classes, x_ii= elements of the main diagonal of the confusion matrix, x_Σ▒i= sum of the pixels of reference class i and x_(i Σ)= sum of the pixels classified as class i.

4.1 Cracks Detection Using ANN Method

There are different classical methods which are used for cracks detection. One of the methods was known as an artificial neural network method. Bakhary (2007) considered applying Artificial Neural Network or ANN towards damage [12]. During the person's investigation, a certain type of ANN model has been created to apply towards Rosenblueth's point estimate method. This method has been verified through the simulation process of Monte Carlo. There has also been an estimation of the statistics of the stiffness. After that, the probability of damage existence was done and calculated based on the probability density function of the current undamaged and damaged states. Such a developed approach was applied to detect simulated damage in a steel frame model and another concrete [13].

There has been the use of ANN or Artificial Neural Networks by different researchers so that they identify the damage location properly and also by getting severity from different types of input as well as output variables. They help to provide an efficient tool in terms of pattern recognition. There have been several studies [10].

ANN and it has been concluded from most of the studies that the Artificial Neural Network or ANNs can provide the correct level of damage identification. This is especially true when the overall structural damage and the related changes in vibration properties are simulated numerically and they are considered error-free. Nonetheless, this needs to be noted that during practice, there could be uncertainties in the overall FE model parameters and there could be some modeling errors that are known to be inevitable [10].

The overall existence of having modeling error in the FE model because of the inaccuracy of physical parameters and structural properties may end up in vibration parameters. Furthermore, having measurement error in the data which is normally used as testing data in the ANN model can also be considered unavoidable. ANN prediction efficiency is mostly dependent on the accuracy of both these components. The existence of such types of uncertainties can also result in a false and inaccurate type of ANN predictions. Therefore, the authors can understand that there should be proper analysis related to the reliability of the Artificial Neural Networks or ANN models for any sort of structural damage detection.

4.2 Cracks Detection by Hybrid Technique

Research has brought in a new method so that the location as well as crack depth on any structure can be identified. One such method is known as a hybrid neuro-genetic technique. In this case, feed-forward multi-layer neural networks are trained through the process of backpropagation to learn about the input-output relation of the whole system [5]. After that, the researchers used a genetic algorithm to find out the different locations of the crack as well as its depth so that the difference from the measured frequencies can be minimized. Using neural networks for damage detection has been developed for many years. This is because they can cope with the different structural damage analysis without considering any intensive computation. Neural networks are considered to be a potential approach through which users will be able to understand and detect the structural damage. For such researches, it is required to have both the modal frequencies and the modal shapes as well for ensuring the neural network training so that the authors can understand more about the structural damage detection [10].

4.3 Discussion

Out of the described methods, the hybrid technique of crack detection provided the most accurate results in detecting cracks with at least 18% of accuracy above the other methods. This is seen as a great outcome from a crack detection method, which may ensure a significant enhancement in terms of identifying and fixing cracks on different surfaces.

In terms of deep learning, one of the challenging things is network training. There are several parameters involved in this and it also requires a huge level of data for training purposes. Some techniques are considered to be efficient whereas some others are not. There is a technique known as per-pixel window-sliding which can be used for crack detection [11]. This process is considered extremely inefficient and could also contribute to a much higher level of cost. However, there is an alternative to using the per-pixel window-sliding where users will be able to utilize the Convolutional Neural Network or CNN for pre-selection purposes that will help to divide the full-size image into few image blocks. Inspection enhancements procedures are also used to properly understand cracks detection. To process the cracks accurately, there have been propositions to use CNN for block-level crack detection [5].

5 Conclusion

Cracks occur when solid structures disintegrate. These include concrete surfaces in which crack detection methods could help identifying any type of cracks, including transversal, longitudinal, and pothole. The challenge for this procedure would be network training, in which several parameters are involved in the determination of the location and severity level of the cracks. This study found out that the hybrid crack detection technique provides more accurate and reliable outcomes due to the fact that it combines both the ANN and ABC algorithms to help the designers locating and analyzing cracks. It is expected that this finding may contribute in answering several questions over the accuracy and reliability of various crack detection methods as well as help providing an appropriate response to the growing discourse over the field of research.

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References

[1] Abella, B.M., Rubio. L. and Rubio, P. (2012), "A non-destructive method for elliptical cracks identification in shafts based on wave propagation signals and genetic algorithm", Smart Struct. Syst., 10(1), 16-20.

[2] Hakim, S.J.S. and Abdul Razak, H. (2013b), "Adaptive Neuro Fuzzy Inference System (ANFIS) and Artificial Neural Networks (ANNs) for structural damage identification", Struct. Eng. Mech., 45(6) 779-802

[3] Li, Z.X. and Yang, X.M. (2008), "Damage identification for beams using ANN based on statistical property of structural responses", Comput. Struct., 86, 64-71.

[4] Rytter, A. and Kirkegaard, P. (1997), "Vibration based inspection using neural networks, Structural damage assessment using advanced signal processing procedures", Proceedings of the DAMAS 97, University of Sheffield, UK.

[5] Mohan, A., & Poobal, S. (2018). Crack detection using image processing: A critical review and analysis. Alexandria Engineering Journal, 57(2), 787-798.

[6] Bucklin, S. (2019). AI Technology Improves Critical Crack Detection. Retrieved from Communications ACM: https://cacm.acm.org/news/237484-ai-technology-improves-critical-crack-detection/fulltext

[7] Purdue. (2019). AI technology improves critical crack detection in nuclear reactors, bridges, buildings. Retrieved from Phys: https://phys.org/news/2019-06-ai-technology-critical-nuclear-reactors.html

[8] Thielemans, L. (2018). How users can detect cracks in concrete bridges using deep learning. Retrieved from Raccoons: https://blog.raccoons.be/detecting-cracks-in-bridges-using-deep-learning

[9] Zhang, K. (2019). DEEP LEARNING FOR CRACK-LIKE OBJECT DETECTION. Retrieved from Digital Commons: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=8747&context=etd

[10] Sitara, S. N., Kavitha, S., & Raghuraman, G. (2018). Review and Analysis of Crack Detection and Classification Techniques based on Crack Types. *International Journal of Applied Engineering Research, 13*(8), 6056-6062.

[11] Ahmadi, A., Khalesi, S., & Bagheri, M. R. (2018). Automatic road crack detection and classification using image processing techniques, machine learning and integrated models in urban areas: A novel image binarization technique. *Journal of Industrial and Systems Engineering, 11*, 85-97.

[12] Bakhary, N., Hao, H., & Deeks, A. (2007). Damage detection using artificial neural network with consideration of uncertainties. *Eng. Struct., 29*(11), 2806-2815.

[13] Parhi, D., & Choudhury, S. (2011). Analysis of smart crack detection methodologies in various structures. *Journal of Engineering and Technology Research*, 139-147.

[14] Clarke. F. R. Constant-ratio rule for confusion matrices in speech communication. Journal of the Acoustical Society of America. 1957,29,715-720.