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Integrating Artificial Neural Networks for Early Detection and Analysis of Building Cracks

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Abstract
Building cracks are a common issue that can have significant consequences, such as structural damage and safety hazards. Detecting cracks at an early stage is crucial to prevent further damage and ensure the safety of building occupants. This paper aims to provide an overview of the causes and types of building cracks and discuss various techniques for their detection and monitoring. The detection techniques include visual inspection, measuring crack width and depth, ultrasonic testing, X-ray testing, infrared thermography, and ground-penetrating radar. The monitoring of cracks is also discussed, highlighting the importance of monitoring and various techniques for it. The prevention and repair of building cracks are also covered in this paper. The prevention measures include proper design and construction techniques, while repair techniques include filling and sealing of cracks. The paper concludes with a Case-Study using ANN model for the prediction of building crack, with a summary of key points and future research directions. The information provided in this paper can be useful for building owners, engineers, and construction professionals in the prevention, detection, and repair of building cracks.

Keywords: Cracks detection, Crack measurement, Visual ground penetration, ANN Model.

1. Introduction
1.1. Background and significance
Building cracks are a common occurrence and can have serious consequences if left undetected and unrepaired. Cracks can compromise the structural integrity of a building, leading to potential safety hazards for occupants. According to [1], detecting and repairing cracks is essential to maintain the safety and longevity of a building. This study is focused on the causes and types of building cracks, as well as various techniques for their detection and monitoring. Additionally, the paper dwells on exposition of the prevention and repair methods to restore the structural integrity of the building. It equally examines the causes and types of building cracks, including natural and human-induced causes and the various types of cracks that can occur. It also discusses the techniques used for the detection and monitoring of cracks, including visual inspection, measuring crack width and depth, ultrasonic testing, X-ray testing, infrared thermography, and ground-penetrating radar. The importance of monitoring cracks was equally discussed, along with various monitoring techniques. Other sections cover the prevention methods, including proper design and construction techniques, and repair methods, such as filling and sealing of cracks. Case study is presented to illustrate the practical application of these techniques using the artificial neural network technique. The final section is the summary of key points and future research directions. The information provided in this paper will be useful for building owners, engineers, and construction professionals in the prevention, detection, and repair of building cracks.

2. Causes of Building Cracks
Past studies have investigated causes of cracks in structural materials. Building is subject to cracks based on so many reasons which include natural causes, human-induced causes, structural failure or problems and others.

2.1. Natural causes Natural causes of building cracks include seismic activity, settling of the ground, and expansive soils. Seismic activity can cause cracks due to the movement of the earth's crust, while settling of the ground can cause cracks as the building foundation shifts. Expansive soils can cause cracks due to their ability to expand and contract with changes in moisture content.

2.2. Human-induced causes Human-induced causes of building cracks include poor design and construction practices, such as inadequate reinforcement or improper mixing of building materials. Additionally, external factors such as nearby construction or excavation can cause ground movement that can lead to building cracks.

2.3. Structural problems Structural problems such as overloading of building components, inadequate support of walls and floors, or inadequate anchorage of building components can also cause building cracks. Other structural problems that can lead to cracks include aging of building materials and deterioration due to exposure to the elements.

Identifying the underlying causes of building cracks is essential for effective repair and prevention measures. Addressing the root cause of the cracks can prevent their recurrence and ensure the long-term structural integrity of the building.

3. Types of Building Cracks

Some noticeable kind of building cracks as observed in [19] include the following:

3.1. Hairline cracks - Hairline cracks are very fine, shallow cracks that are less than 0.1mm in width. They are often found in plaster, drywall, or concrete surfaces and are typically cosmetic in nature. Hairline cracks may occur due to shrinkage during the curing process or natural expansion and contraction of building materials. While they do not pose a significant structural risk, they can affect the aesthetic appeal of the building and may allow moisture to penetrate the surface, leading to further damage.

3.2. Settlement cracks - Settlement cracks occur due to the movement or shifting of the building's foundation or ground beneath the foundation. These cracks are often found in walls or floors and typically run diagonally from the corner of a door or window. Settlement cracks can be a serious structural issue if they continue to widen over time.

3.3. Expansion cracks - Expansion cracks occur when building materials, such as concrete or masonry, expand and contract due to changes in temperature or moisture content. These cracks are typically found in concrete slabs, foundations, or walls and can range from hairline to several inches in width.

3.4. Structural cracks - Structural cracks occur due to issues with the building's design or construction, such as inadequate reinforcement or support of walls and floors. These cracks can be severe and may be accompanied by other signs of structural damage, such as uneven floors or doors that do not close properly.

3.5. Cracks due to external factors - Cracks due to external factors can occur as a result of nearby construction or excavation, changes in soil conditions, or natural disasters such as earthquakes or floods. These types of cracks can vary in severity and may be difficult to detect without a thorough inspection.

3.6. Settlement cracks - Settlement cracks occur due to the movement or shifting of the building's foundation or ground beneath the foundation. These cracks are often found in walls or floors and typically run diagonally from the corner of a door or window. Settlement cracks can be a serious structural issue if they continue to widen over time.

3.7. Vertical cracks - Vertical cracks are often found in concrete walls or masonry, and run straight up and down. They may be caused by settling, natural expansion and contraction of building materials, or structural issues.

3.8. Horizontal cracks - Horizontal cracks are typically found in concrete walls or masonry and run parallel to the ground. These cracks may be caused by excessive pressure or weight on the building, such as from nearby construction or improper soil grading.

3.9. Diagonal cracks Diagonal cracks can occur in both walls and foundations and typically run at a 45-degree angle. They may be caused by a combination of factors, such as settling, structural issues, or soil movement.

3.10. Cracks due to moisture Cracks due to moisture can occur in any building material and may be caused by a variety of factors, including excessive moisture or water damage, freeze-thaw cycles, or improper ventilation. These cracks can range from hairline cracks to more significant structural damage, and can be difficult to detect without a thorough inspection.

Understanding the different types of building cracks is essential in determining their underlying causes and developing effective repair and prevention strategies. It is important to address building cracks promptly to prevent further damage and ensure the safety of building occupants.

4. Detection Techniques

Crack detection methods involve various techniques for identifying cracks and other defects in building materials [2,3]. These methods are essential in determining the severity of the damage and developing appropriate repair and maintenance strategies to ensure the safety of building occupants [4].

4.1. Visual inspection - Visual inspection is the most common and straightforward method of detecting cracks in buildings. This technique involves a thorough visual examination of the building's exterior and interior, looking for cracks or other signs of damage. A trained professional or building owner can perform the inspection. During the visual inspection, the inspector looks for cracks in walls, ceilings, floors, and other structural elements of the building.

4.2. Measuring crack width and depth Measuring crack width and depth can provide valuable information about the severity of the crack and potential risks to the building's structural integrity. This technique involves using specialized tools to measure the width and depth of the crack accurately. The measurements can be used to determine the best repair strategy for the crack.

4.3. Ultrasonic testing Ultrasonic testing involves using high-frequency sound waves to detect cracks and other defects in building materials. The technique is non-destructive and can be used to identify cracks that are not visible to the naked eye. Ultrasonic testing is commonly used to detect cracks in concrete structures.

4.4. X-ray testing X-ray testing is a non-destructive technique that uses X-rays to identify cracks and defects in building materials. The technique is commonly used to detect cracks in steel structures, but can also be used to detect cracks in other building materials.

4.5. Infrared thermography Infrared thermography is a technique that uses thermal imaging cameras to detect changes in temperature caused by cracks or other defects in building materials. The technique is non-destructive and can be used to detect cracks that are not visible to the naked eye.

4.6. Ground-penetrating radar Ground-penetrating radar is a non-destructive technique that uses radar pulses to detect cracks and other defects in building materials. The technique is commonly used to detect cracks in concrete structures, but can also be used to detect cracks in other building materials.

Choosing the appropriate detection technique depends on the type of building and the nature of the crack. A combination of techniques may be necessary to accurately detect and assess the severity of building cracks. Regular building inspections and maintenance can help to prevent cracks from occurring and ensure the safety of building occupants.

5. Monitoring of Cracks

5.1. Importance of Monitoring

Monitoring of cracks is an essential step in building maintenance and safety. Cracks can propagate over time and cause structural damage, potentially leading to catastrophic failure. Continuous monitoring of cracks helps in detecting any changes in the crack size or shape, which can indicate potential structural problems. Early detection of changes can help to prevent further damage and ensure the safety of building occupants.

5.2. Techniques for Monitoring

Several techniques are available for monitoring cracks in buildings, including: Crack gauge, Inclinometer, Strain gauge, Crack monitoring software,

Crack Gauge: Crack gauge is a simple device used to monitor the width of the crack. The device consists of two arms that are mounted on either side of the crack. The arms have a calibrated scale that indicates the width of the crack. The gauge is attached to the building using screws or adhesive.

Inclinometer: Inclinometer is a device that measures the angle of the crack relative to the ground. It consists of a probe that is inserted into the crack and a display unit that shows the angle of the crack. Inclinometers are commonly used to monitor the stability of slopes and retaining walls.

Strain Gauge: Strain gauge is a device that measures the strain or deformation of a material. It consists of a sensor that is attached to the surface of the building, and a display unit that shows the amount of strain. Strain gauges are commonly used to monitor the deformation of concrete and steel structures.

Crack Monitoring Software: Crack monitoring software is a digital tool that uses cameras or sensors to monitor cracks in buildings. The software can detect changes in crack size and shape, and provide real-time alerts if any changes occur.

5.3. Case Study

Classical methods of crack detection is a common scenario. There is need to shift away from the classical approach to a much more robust method. For instance, a study conducted by [5] focused on investigation of crack using natural frequency; [6] focused on the detection of crack location and size in structures using higher harmonics of excited frequency; [7] focused on the effect of crack on Natural Frequency by using FEA. Other classical techniques of crack detection in structures are documented [8,9,10]. Case studies have shown that crack monitoring is an effective technique for detecting changes in crack size and shape if a good method is implemented. For example, a study conducted on a concrete showed that continuous crack monitoring on a Structural Beam using a simplified analytical method based on artificial neural network model proffered a satisfactory solution within the shortest possible period of time [11]. Computational intelligence techniques have helped in detecting the development of new cracks and changes in existing cracks. The early detection of changes allowed the experts to take appropriate measures to prevent further damage.

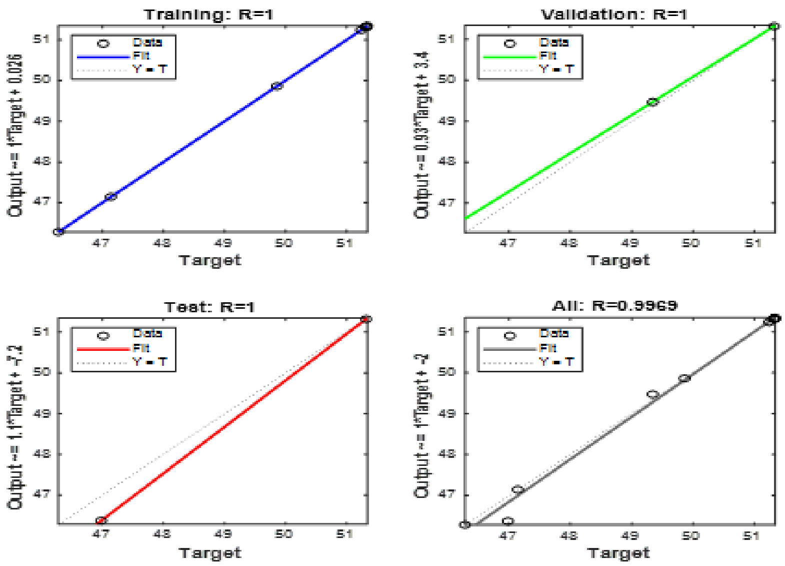
Monitoring of cracks in buildings using soft computing techniques is therefore essential for ensuring the safety of building occupants and preventing further damage to the structure. Continuous monitoring using appropriate techniques and tools can help in detecting changes in crack size and shape, allowing for timely repairs and maintenance.

5.4. Artificial Neural Network Model

Computational intelligence techniques are becoming very popular especially the ANN and Fuzzy model which are highly effective model as demonstrated in previous studies. ANN Model for Cost Optimization in a Dual Source Multi-Destination System [12]; for cost analysis in dual-source multi-destination system during cost optimization [13]; for Modelling of Nicotiana Tabacum L. Oil Biodiesel Production [14]; for generic purposes [15] and for petroleum studies and reservoir management [16]; In diverse area of mining and blasting operations. Case study is presented using a dataset based on crack information collected from a construction site. The ANN model was used to predict the experimental result using vibration based on natural frequency. For the dataset obtained from the structural beam, a demonstration of the power of ANN is given. The sigmoid function indicates that there are two layers at the input level and ten hidden layers and four output layers. The most recent version of MATLAB was used for the analysis, and 30% of the dataset was divided into sections for testing and validation and 70% of the dataset was used for training. When the R^2 value falls within the range, the solution obtained using ANN, as presented in Table 1, demonstrates a satisfactory solution.

Table 1: ANN Result for MSE and R value of Measured Vibration based on Natural Frequency.

	Samples	MSE	R
Training	70%	0.00346×10^{-4}	1.0
Validation	15%	0.0730×10^{-2}	1.0
Testing	15%	0.0611×10^{-2}	1.0



The dominance and predictive power of model strategies are assessed using statistical indicators. The equations for calculating the aforementioned statistical variables are provided in systems of Equations 1-3.

$$R = \left(\frac{\sum_{m=1}^{n}(Y_{Pred.m} - y_{Pred})(Y_{exp.m} - y_{exp})}{\sqrt{\sum_{m=1}^{n}(Y_{Pred.m} - y_{Pred})^2 \sum_{m=1}^{n}(Y_{exp.m} - y_{exp})^2}} \right) \quad 1)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_{i,P} - Y_{1,e})^2}{\sum_{i=1}^{n}(Y_{i,P} - Y_{e,ave})^2} \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_{i,e} - Y_{i,p})^2}{n}} \quad (3)$$

Yi represents the observed value of samples, Ye represents the estimated value of samples, N represents the number of samples, A, B, and C denote independent variables, and ij is the coefficient of linear terms. Ypred represents the predicted value of samples. Yexp represents the experimental value.

The training and testing results for the frequency dataset were satisfactory. The experimental framework was created around the data, which were portioned into training, validation, and testing sets. For evaluation and analysis, the coefficient of determination (R^2), mean squared error (MSE), root mean squared error (RMSE), and regression coefficient (R) were used as statistical measures. The outcome displays a very low MSE and RMSE. The outcome demonstrates that the output and the target data have a linear relationship. This demonstrates the model's high prediction accuracy.

Since the excitation occurred at the first natural frequency, the amplitude of the acceleration responses increased from the fixed end to the free end of the cantilever beam, as was expected. The acceleration response represents a pure sine wave in the healthy condition of the cantilever beam. Despite appearing to be less than in the healthy state, the amplitude pattern is identical in the crack condition and is caused by the crack itself. The same changes were observed in an experiment carried out by [11]. This technique can therefore be used to determine the frequency of cracks mode shapes, crack locations and natural frequencies.

The experimental framework was built around the data by using ANN feed-forward backpropagation algorithm with sigmoid function of layers and seventy percent of data for training while thirtt percent was used for validation, testing. The result of the model is an indication that there is minimum detection of crack on the building test sample. This is because minimal changes in natural frequencies were very small. ANN in this study has proved to be a suitable technique for crack detection and analysis.

6. Prevention and Repair of Building Cracks

6.1. Prevention Measures: Preventing cracks from forming in buildings is essential for ensuring the safety and longevity of the structure. Some effective prevention measures include:

a. Proper design and construction: A building should be designed and constructed to withstand the loads and stresses it will be subjected to during its lifetime. Using high-quality building materials and following proper construction practices can help in preventing cracks from forming.
b. Proper maintenance: Regular maintenance of the building, including cleaning gutters, repairing leaks, and maintaining the foundation, can help in preventing cracks from forming.
c. Controlling moisture: Moisture is a common cause of building cracks, and controlling moisture can help prevent cracks from forming. Proper drainage systems, waterproofing, and ventilation can all help in controlling moisture.
d. Soil stabilization: Soil movement is a significant cause of building cracks. Stabilizing the soil around the foundation can help in preventing cracks from forming.

6.2. Repair Techniques: If cracks have already formed in a building, they must be repaired to prevent further damage. Some effective repair techniques include:

a. (a). Injection of epoxy or polyurethane: Epoxy or polyurethane can be injected into the cracks to fill and seal them. This technique is effective in preventing water from entering the crack and causing further damage.
b. (b). Reinforcement: Reinforcing the damaged area with steel bars or carbon fiber can help in preventing further cracking.
c. (c). Resurfacing: If the cracks are small, resurfacing

the affected area with a fresh layer of concrete can help in preventing further damage.

d. (d). Replacement: If the damage is severe, replacement of the affected area may be necessary.

In conclusion, prevention measures and timely repair of building cracks are essential for ensuring the safety and longevity of the structure. Proper design and construction, regular maintenance, controlling moisture, and soil stabilization can all help in preventing cracks from forming [18]. If cracks have already formed, injection of epoxy or polyurethane, reinforcement, resurfacing, or replacement can all be effective repair techniques.

6.2. Summary of key points

In this article, various techniques for detecting cracks in buildings have been discussed. The definition of crack is detailed and the reasons why early detection of cracks is necessary. Some common methods used to detect cracks, such as visual inspection, laser scanning, and acoustic emission have been exposed. Then the application of artificial neural network algorithm was used to demonstrate and facilitate crack monitoring and detection. Generally, it is clear that there is no one-size-fits-all solution for detecting cracks in buildings, and that different techniques will be more effective in different situations. However, by combining multiple methods and technologies, it is possible to improve crack detection and prevent serious damage to buildings and their occupants.

6.3. Future research directions: There are several areas where further research could be conducted to improve crack detection in buildings. For example:

a. Developing new sensors: New sensors that are more sensitive and can detect cracks at an earlier stage could be developed. These sensors could be integrated into building materials during construction to monitor the building's health continuously.
b. Combining multiple techniques: By combining different crack detection techniques, such as visual inspection, laser scanning, and machine learning algorithms, it may be possible to improve accuracy and efficiency.
c. Developing new algorithms: As machine learning algorithms become more advanced, they could be used to detect subtle cracks that are not visible to the naked eye. This could involve developing new deep learning architectures or training models on larger datasets.
d. Testing in real-world scenarios: Further research could be conducted to test the effectiveness of different crack detection techniques in real-world scenarios. This could involve collaborating with building owners and managers to monitor cracks in their buildings over an extended period.

By continuing to invest in research and development in this field, it may be possible to prevent serious damage to buildings and save lives in the future.

Conclusion

In conclusion, building cracks can have serious consequences if not detected and repaired promptly. This paper has provided an overview of the causes and types of building cracks and discussed various techniques for their detection and monitoring. The detection techniques discussed include visual inspection, measuring crack width and depth, ultrasonic testing, X-ray testing, infrared thermography, and ground-penetrating radar. The monitoring of cracks is also important to detect any changes in crack patterns and sizes. Prevention measures, such as proper design and construction techniques, can help to avoid cracks, while repair techniques, such as filling and sealing of cracks, can help to restore the structural integrity of the building. It is important to note that no single technique is suitable for all types of cracks, and a combination of techniques may be required for accurate detection and monitoring. The effectiveness of detection and repair techniques can also depend on the expertise of the personnel involved. Future research directions can include the development of new and more accurate techniques for crack detection and monitoring, as well as the evaluation of the long-term effectiveness of repair techniques. In summary, this paper provides useful information for building owners, engineers, and construction professionals in the prevention, detection, and repair of building cracks, which can ultimately lead to safer and more durable buildings.

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