Survey on Automatic Crack Detection and Measurement Techniques

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Abstract: ***Crack detection and measurement is one of the most important structural healths monitoring method. The cracks not only affect the visual appearance but rather the shorter life span of structure and the effect will be catastrophic, if it is not detected and repaired on time. The system designer now has an array of available choices of crack detection methods. For the evaluation of different crack detection method, here presents a comparison among different techniques like wavelet transform, neural network and particle filter. Survey among these techniques based on certain criteria exhibits a better option to choose the efficient method for crack detection.***

Keywords: Crack detection, Wavelet transform, Neural Network, Particle Filter

1. Introduction

Crack detection and measurement plays as an inevitable role in the evaluation of fitness of structures like buildings, roads, pavements, etc. The presence of crack not only affects the visual appearance, but instead it transforms the matter of safety to be a big challenge. Based on the detected and measured crack further maintenance measures can be undertaken.

The main causes of crack formation are thermal movement, where it depends on number of factors like temperature variations, dimensions, properties of materials used and the exposure of walls to direct solar radiation. Corrosion of reinforcement poor construction practices, poor structural design and specification also results in the occurrence of cracks. In addition to these, pavement distress is caused due to heavy vehicle traffic and changing weather conditions. So it becomes to be an essential task to monitor these defects before repair costs becomes too high.

The presence of crack gradually leads to shorter life span of structures. Many structures had collapsed due to this. For example, Can Tho Bridge in Vietnam (2007), Kadalundi River Rail bridge in India (2001), Rana Plaza Building in Bangladesh (2013).These tragical incidents are due to structural failures and highlights the need for periodical maintenance. The structural maintenance work includes repairing by concrete reinforcement, etc

Crack detection and measurement can be done in many ways and generally as: human inspection where it make use of traditional measurement system on manually detected crack; microscopic inspection done by different special tools and machine vision inspection where automatic crack detection and measurement is done [9].

The main contribution and novelty of this work is to survey on different automatic crack detection and measurement methods; i.e., wavelet transform, neural network, particle filter. Wavelet transform : it is the representation of a function by wavelets and it considers both the time and frequency domain of the signal. Hence, it can observe the changes in pattern over time. Moreover it can be applied to non – stationary signals or data where other techniques like Fourier transform fails. Hence it can be used in crack detection where it is a non – linear problem.

Neural network approach, mainly relies on the trained data is used for detecting the particular damage or a crack in the inputted image and further it classifies the type of crack i.e., alligator, longitudinal, linear, etc [6].

Particle filter, another approach for automating the crack detection and measurement are a set of genetic type particle Monte Carlo methodologies that solve the filtering problems. This methodology solves non –linear filtering problems[10] i.e., estimating the internal states in dynamical systems aiming at finding the conditional probability of the states of Markov process based on some noisy and partial observations. This approach is used for crack detection method.

These techniques described in detail further sections and it is compared as follows:

In section 2, different a technique for crack detection is described. Section 3 illustrates the performance measurement parameters and their comparison result. Finally, section IV presents the conclusion.

2. Crack Detection Techniques

2.1 Neural Network

Neural network, i.e., connectionist system and is a computational approach modeled based on biological brain which is a collection of large neural units that exhibits best performance if the system is tolerant to errors. Neural network is a complex adaptive system, i.e., it can change its internal structure based on the information flows through it makes it perfect for learning. Most of neural networks have some form of learning rule that modifies the weights of internal connections based on the input that is fed to the network. i.e., it learns by example. The diagrammatic representation of a neural network can be given as:

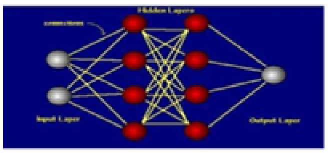

Figure1: Neural network representation

It mainly has three layers: input layer, hidden layer, output layer and each connection have weights assigned. If the network results a poor output, the system adapts by altering the weight to improve the subsequent results and is based on some learning rule. The supervised technique has two steps: training and testing. Training is done for classifier training where human expert manually selects images that is to be trained and during testing the image is classified based on the trained data [7].

Delta rule is one of the learning rule and more utilized by backpropagational neural network (BPNNs)[6]. i.e., backward propagation of error. Back propagation performs gradient descendent within solutions vector space towards a global minimum of error. i.e., it produces solution with lowest possible error. These criteria makes it possible explore the back propagation neural network in many image processing and pattern recognition techniques. Back propagation needs a known desired output for each input value thus it can calculate the loss function gradient, hence it becomes to be supervised learning method

For each neuron *j*, the output can be calculated as:

$$O_j=\phi(net_j)=\phi\left(\sum_{k=1}^{n} W_{kj}\, O_k\right) \quad (1)$$

Where oj is the output. The input net j to a neuron is the weighted sum of outputs ok and wij is the weight between neurons *i* and *j*.

This supervised technique is widely used in automatic Structural Health Monitoring (SHM), that includes crack detection in pavement, road, building. Neural network can be used to automatically divide as cracked and non – cracked concrete surface where back propagation algorithm is used for training. Moreover BPNN can be used for distinguishing images between linear, transversal and alligator cracks to acquire high recognition accuracy. To improve the accuracy further, image preprocessing steps like enhancement, segmentation and crack information extraction can be done and also finds the feature parameters like crack length or width, cracking area, etc.

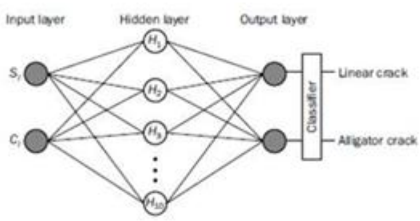

Figure 2: BPNN structure in [6]

BPNN is most widely used for extracting the useful information due to its simplicity and great power. Supervised technique for automatic crack detection includes splitting the image into two subsets: training image subset containing the manually selected crack images for classifier training and test image subset composed of images that is to be automatically classified [7]. The training image subset have a pattern vector x, for each element x_i, of pattern vector x, possible class y_i is assigned. The training set is given as:

$$T = \{(x, y)\ldots\ldots(x_n, y_n) y_i \in \{c_1, c_2\}\} \quad (2)$$

Where, n: number of pattern vector x, c_2: regions with crack
pixel, c_2 : region without crack pixel

Based on this supervised classification strategies are tested. The results shows that all the detected cracks were correctly classified into different types. Neural networks, i.e., BPNN makes it possible to solve non – linear or dynamic problems like crack detection even if the data is large and the main disadvantage is that it takes more time hence reduces the processing speed.

2.2. Wavelet Transform

Wavelet transform is most popular for time – frequency transformations. It is mainly used to extract information from many different kinds of data. i.e., the benefit of using the wavelets is the ability to perform local analysis of signals that helps to reveal the hidden aspects of data where other signal analysis techniques fail to find. Wavelet transform is called as global image processing method since it focus on the entire image [3].This property is relevant since it can be used in applications for detecting damage. Hence wavelet analysis can be efficiently used in many fields like structural and machine health monitoring. The wavelet transform is of two: continuous wavelet transform and discrete wavelet transform.

Structural health monitoring includes damage detection, crack detection. The local analysis is required to extract the local characteristics of crack as the direction and connectivity and thus the wavelet analysis. The crack detection can be done by techniques like wavelet transform, Fourier transform, Sobel filter, Canny filter among which wavelet transform exhibits better performance and is more reliable than other methods [3]. The equation for wavelet transform can be given as:

$$F(a,b)=\int_{-\infty}^{\infty} f(x)\, \Psi^{*}_{(a,b)}(x)dx \quad (3)$$

Where * is the conjugate symbol and ψ denotes some function Scale and translation are the two basis parameters of wavelet analysis [2]. Hence multi resolution representation for non – stationary signals can be obtained. Wavelets can also be used to identify non – linear structural systems. This helped to detect the stiffness and damping coefficient of structure without any assumption on non linear characteristics of structure. The crack detection can be done by using continuous wavelet transform [1].

The general expression of continuous wavelet transform is represented as:

$$F(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty}\Psi\left(\frac{t-b}{a}\right)x(t)dt \quad (4)$$

Here ψ*: base* atom, is a zero average function
a: scale parameter, b: translation parameter

2D CWT is performed for both 0° and 90° directions at much different scale and complex representation for the same have been developed belongs to the crack.

Selection of proper scale is important because for small damages higher scale is considered. Wavelets like Haar, Ciof, Db is useful in crack detection at low scale. Hence, wavelet transform offer a simultaneous localization of time and frequency domain, computationally fast while using fast wavelet transform and separate fine details and identify coarse details hence this approach can perform well in crack detection.

2.3. Particle Filter

Particle filter is another approach for automating the crack detection process. It is originally developed as a tool for the purpose of tracking the state of a dynamic system. The particle filter method, in high dimensional problems founds to be computationally tractable and is used for solving the state space models. Moreover, it is a non - linear filtering method and provides improved performance over other non linear filtering methods. Particle filtering technique is applied in mobile robotics in which it helps in industrial engineering, process control, fault diagnosis task. The higher dimensional problems like robot mapping, people tracking, which is a big challenge are solved with the advanced variants of particle filter.

Particle filter is a non - parametric state estimator. i.e., it does not make any assumption on measurements. The particle filter is evolved from Monte - Carlo method. The main aim is to find the distribution of *f* of the state vector and starting from an initial distribution *g*, estimates that The particle filter is mostly used when the posterior density and the observation density are non - Gaussian. Posterior density is represented as $p(X_k |Z_k)$ where Z_k denotes all the observations $(z_1, z_2, \ldots z_k)$ up to time *k*.

This idea of particle filter can be used in crack detection by approximating the probability distribution by a weighted sample set

$$S = \{(s^{(n)}, \pi^{(n)}) |n= 1\ldots\ldots N\} \qquad (7)$$

where N represents number of particles used.

closely approximates the real value of state vector *x*. The weight assigned to particle x can be given as,

$$w(x) = f(x) /g(x) \qquad (5)$$

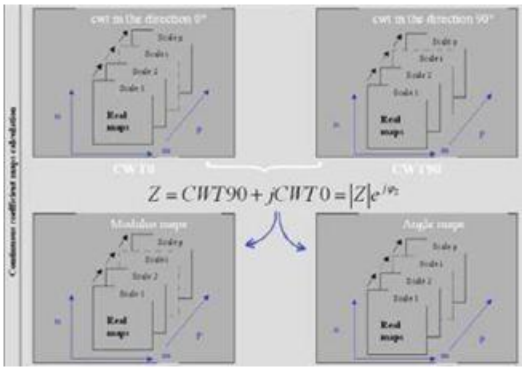

Figure 3: Complex coefficient map

Here, mother wavelet chosen is the Mexican hat function after testing on various images. Later on, complex number taken considers the real part and imaginary part in the direction 0° and 90° respectively and the complex coefficient map, modulus map and phase maps are built on different scale computed [1].The main idea is that the angle information allows to consider only the coefficients that. By updating the weight w(x), the convergence of initial probability distribution of g(x) to desired f(x) can be controlled. Hence, particle filter algorithm approximates $p(x_k).p(x_k)$ is the probability that the state vector xk can be located at time instant *k* in a certain state space region. The input sequence $a_1, a_2, \ldots a_k$ generates the *k* output measurements $z_1, z_2, \ldots z_k$, a state vector $x_k^{[m]}$ belongs to set of particles X_k where the real state vector x_k is accurately approximated and the probability is given as

$$X_k[m] \sim p(x_k |z_1 : k, a_1 : k) \qquad (6)$$

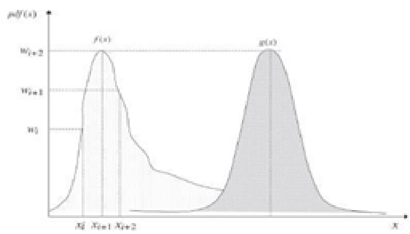

Figure 4: Convergence of initial probability of *g(x)* to desirable final *p(x)* through resampling

The sample set is obtained by propagating each sample according to the system model. Based on the observation made each element in the set is weighted and then N samples are drawn with replacement by taking a sample probability

$$\pi(n) = p(z_k | X_k = s_k^{(n)}) \ (8)$$

The particular number of particles N is chosen that act as a tradeoff between quality and processing speed which is the most important parameters to measure the performance. The larger crack is expected; larger should be the chosen number of particles N.

3. Discussion

This survey paper on various techniques for automating the crack detection and measurement aims at comparing the performance and thus the efficient way to choose the better technique. The overall performance of the techniques is decided by various parameters like processing time or speed, error rate, accuracy, complexity, computation cost. The accuracy is influenced by the error rate.

Table 1: Performance Comparison

Techniques	*Accuracy*	*Speed*	*Computational cost*
Wavelet Transform	Fair	Fair	High
Neural Network	High	Slow	High
Particle Filter	Fair	Fast	Low

Each technique has its own advantages and disadvantages. i.e., the techniques will results in accurate result but at the same time it speed might have reduced when compared with other. The advantages and disadvantages of the techniques can be illustrated in the table given below:

Table 2: Advantages and disadvantages

Techniques	Advantages	Disadvantages
Wavelet Transform	Separate fine details, improves quality	Cannot automate wider number of texture
Neural Network	Solve larger problems, more accurate	Takes more time to train
Particle Filter	Solves state space model, easy to implement	Only approximate solution, varies accuracy

4. Conclusion

This paper contributes an efficient approach to survey on automating the crack detection and measurement techniques. Here, provides a framework for comparing different techniques like wavelet transform neural network and particle filter. The performance of each technique is evaluated based on some performance comparison parameters or criteria including processing time, accuracy, complexity, etc. The comparison result shows that each technique outperforms one another based on the parameter considered vice verse.

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