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Machine Learning in Self-Sensing Concrete illustrated witha strategic structures of Ladakh Region- a Report

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ABSTRACT: Sensing concrete has the capability to sense its condition and environmental changes, including stress or force, strain (or deformation), crack, damage, temperature, and humidity, by incorporating functional fillers. In addition to having highly improved mechanical properties, sensing concrete has multifunctional properties, such as improved ductility, durability, resistance to impact, and, most importantly, self-health monitoring due to its electrical conductivity capability, allowing damage detection without the need for an external grid of sensors.

Keywords: Concrete crack; concrete structure; artificial neural network; convolution neuralnetwork, deep learning, transfer learning, image classification.

I. INTRODUCTION:

Concrete, the most commonly used structural material for the construction of infrastructure, from buildings to highways, dams, tunnels, bridges, high-rise towers, and sewage systems.Produced by mixing water, aggregates, and cement and allowing them to harden, concrete is a durable, affordable, aesthetic, and readily available composite material. However, physical effects, including surface abrasion or erosion, cracking, aging, temperature variation and crystallization of salts in pores, and penetration of water and fire or frost actions, associated with deleterious chemical effects such as alkali-aggregate reaction, carbonation, sulphate attack, and corrosion of reinforcing steels, would cause the deterioration of concrete. The absence of advanced design and condition assessment tools and timely maintenance also plays a considerable role in the failure of concrete structures.

Therefore, surveillance, evaluation, and assessment of the “health” of concrete structures at an early stage to alleviate deterioration or avoid sudden accidents are of great importance to the extension of the service life and the security of lives and property. Inspired by the strategy implemented in a human system, the process of monitoring changes that occur within concrete structures and providing real-time information of structural conditions for safety assessment and afterward maintenance planning is known as structural health monitoring. To achieve this, an entire SHM system should include a sensory system; a data acquisition, transmission, and management system; and an evaluation system. The fundamental part is to establish a stable and reliable sensing system, like a “nervous subsystem,” using appropriate sensing techniques.

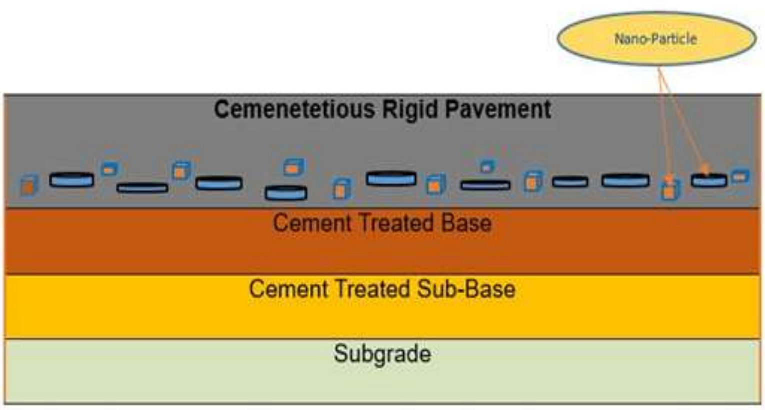

Figure 1: Cementitious Rigid Pavement with Nano-Particles

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To inspect damage in concrete structures, it can be realized with the help of techniques involving strain measurement such as strain gauges or vision-based measurement such as video cameras. To measure temperature and humidity inside concrete structures, the use of optical fiber sensors such as the fiber Bragg grating, FBG sensor has been very common. Sensing concrete, also known as intrinsic self-sensing, self-monitoring, or self-diagnosing concrete, is fabricated through incorporating some functional fillers such as carbon fibres, carbon nanotubes, graphene, and nickel powder into conventional concrete. The functional fillers with intrinsic sensing properties usually are electrically conductive in nature. Well distributed functional fillers at a critical concentration will form an extensive conductive network inside the concrete composite, making the composite conductive. Changes in the composite caused by external forces or environmental actions disturb the conductive network, leading to changes in the composite's electrical properties usually electrical resistance. With this principle, stress or force, strain or deformation, crack, damage, temperature, and humidity under static and dynamic conditions can be detected. Figure 1 presents the sensing concrete principle where a conductive network constituted by functional fillers acts as a "nervous system" to transduce signals stimulated internally and externally to a computing centre, i.e., a "brain," mimicking human behaviour. Compared with other smarter sensors used in SHM, sensing concrete has inherent hostile compatibility and an identical lifespan due to its cement-based property when embedded inside concrete structures. In addition, with the functional filler reinforcement, sensing concrete exhibits remarkably enhanced mechanical properties and durability over the conventional concrete. The versatile, controllableand easy-to-scale features of the fabrication process enable a great potential for mediating sensing concrete with controlled composition, dimension, configuration, and function to fulfil various engineering applications. Therefore, this smart material can be employed to produce intelligent infrastructure integrated with sensing and health monitoring abilities, thus improving serviceability, safety, reliability, and durability of the infrastructures.

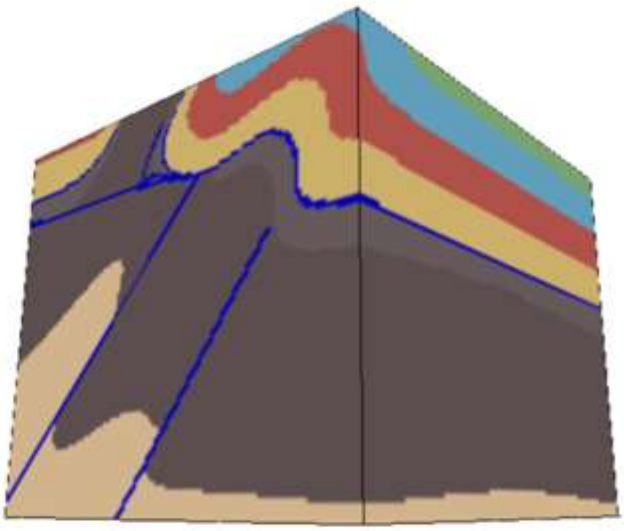

Figure 2: Crack developed in concrete

Sensing concrete, a branch of smart concrete, refers to concrete materials and structures possessing properties to sense various physical and chemical parameters related to structural integrity, durability, and reliability in a generalized sense. On the basis of whether one or multiple sensing elements being integrated, the sensing concrete can be classified into non-intrinsic self-sensing concrete and intrinsic self-sensing concrete. For the non-intrinsic self-sensing concrete, as the name implies, external sensors or actuators such as strain gauges, optical fiber sensors, piezoelectric ceramics, electrochemical sensors, shape memory alloys and conductive polymer composites are embedded attached, or interfaced to enable the sensing functions in concrete structures for structural health monitoring. In spite of generally using concrete materials as supporting structures, the function and performance of non-intrinsic self-sensing concrete is heavily determined by the integrated sensing elements, thus causing difficulties in mass production, high cost, signal acquisition, maintenance, etc.

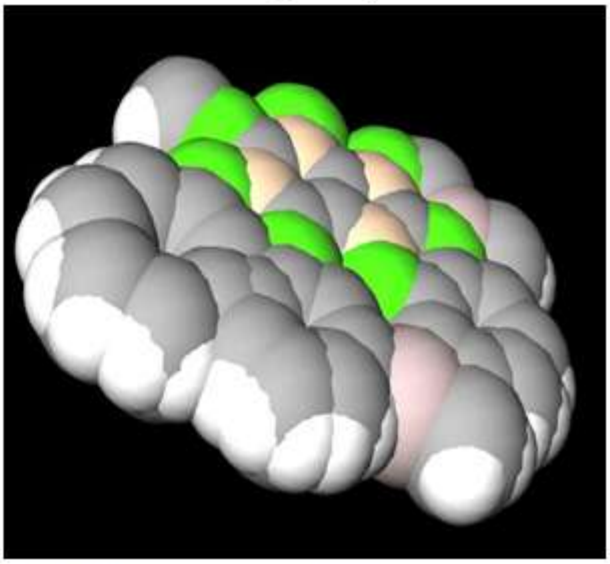

Figure 3: Illustrated molecular bonding of nano-particles

Composition of Sensing Concrete

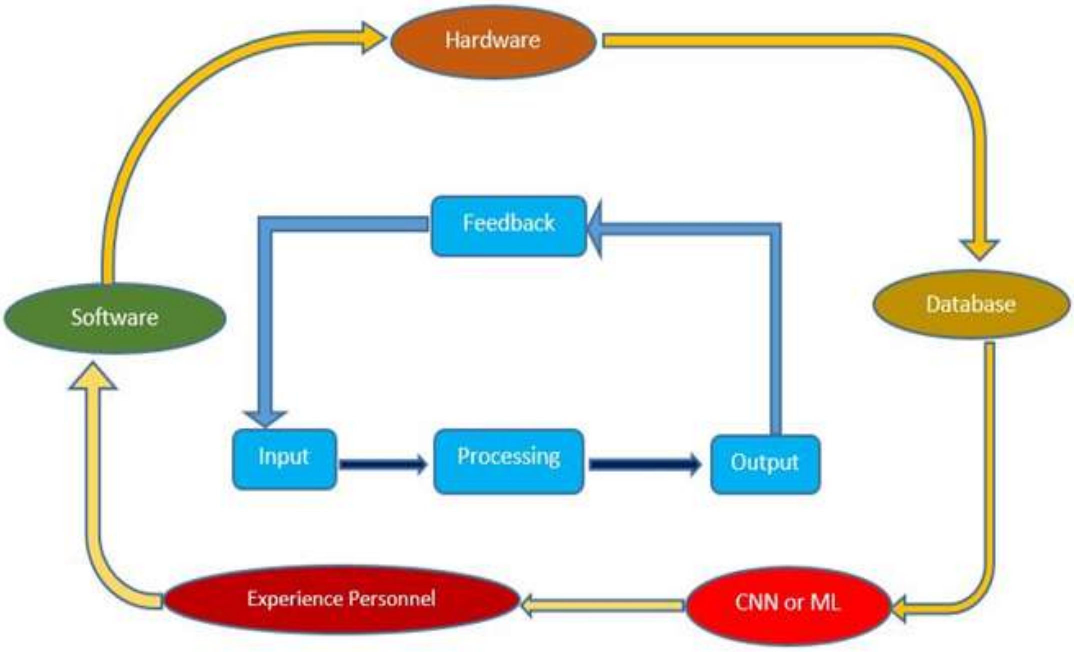

Figure 4: Illustrated process of ML in Concrete Crack Detection

As a type of smart/functional composites, sensing concrete is generally comprised of two major phases: matrix materials and functional fillers. The matrix materials that serve as a binder as well as provide structural functions are cement-based composites including cement paste only Portland cement, cement mortar, Portland cement and fine aggregates and concrete, Portland cement and fine and coarse aggregates. Apart from Portland cement-based composites, sulfo-aluminate cement, geopolymer cement and asphalt concrete have also been reported for using as matrix

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materials of sensing concrete. The mechanical behaviours e.g., ultimate stress and strain, Young's modulus, and Poisson's ratio and sensing performance e.g., sensitivity, repeatability, compatibility, and durability of sensing concrete are highly dependent on the type and mix proportion of matrix materials. The functional fillers play an essential role in providing sensing ability as well as enhanced structural performance. The functional fillers varying from macroscale to nanoscale, fibrous to particle, single to hybrid, and carbonaceous to metallic should be electrically conductive and chemically stable. Recent developments in nanomaterials have stimulated the use of functional fillers at the nanoscale. Particularly, promising functional fillers are nano-carbons including CNTs, carbon nanofibers CNFs, nano-carbon blacks NCBs, and multilayer graphene MLG due to their excellent mechanical, thermal, and electrical properties.

Sensing mechanisms

The sensing behaviour of sensing concrete is essentially derived from variations in its electrical properties due to internal or external actions, in particular, electrical resistivity. However, the manner affecting the electrical conduction is different for sensing concrete working with mechanical deformation or without mechanical deformation as explained below.

With mechanical deformation, several changes are expected when sensing concrete is subjected to external force:

- Change of intrinsic resistivity of functional fillers, which is attributed to stress-induced local bonding deformation.
- Change of bonding between functional fillers and matrix, i.e., change of contact resistivity between filler and matrix due to filler pull-out and push-in upon tension and compression.
- Change of contact between functional fillers. The external force induces rearrangement and orientation of functional fillers, leading to the formation and destruction of effective conductive paths.
- Change of tunnelling resistance between functional fillers, which is attributed to the variation of the inter-particle properties.
- Change of capacitance. Fibrous and flaky fillers can be regarded as capacitance plates due to the ionic conduction of a concrete matrix. The external force leads to variations in the capacitance plate distance and the relative dielectric constant, resulting in the variation in capacitance.
- By creating a conductive concrete, new possibilities for strain-sensing and damage detection systems are given. Whereas, cement-based sensors have to be embedded to multiple locations of a structural element to form a sufficient sensory system and to determine the current health status, the whole element would be conductive with coated aggregates. This gives the opportunity to monitor any part of a structural element and not just one or multiple specific locations. A method, which is called electrical impedance tomography could be enable strain-sensing and spatial damage detection by creating a damage map of the element. To achieve a proper sensing, electrodes have to be placed around a structural element, which enable the flow of a current through a structure. By measuring the resistivity of the concrete between two opposite electrodes a resistivity mesh can be created, which gives information about strain or damage. This method of monitoring the structural health was investigated by Gupta et al., who created conductive concrete plates with drilled holes to study the behaviour of this method, when it is applied to concrete containing CNT thin film-coated aggregates. By creating a concrete with coated fine and coarse aggregates they achieved a very exact sensing behaviour of the composite.

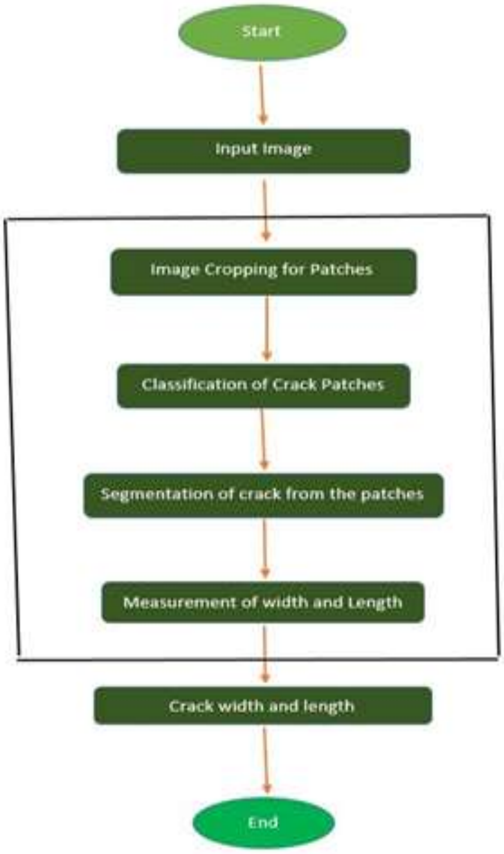

Figure 5: Flowchart of the Processes involved in Crack Detection

Machine Learning in Crack Detection:

Machine learning refers to computer algorithms learning important patterns or rules by itself based on given data without being explicitly programmed. ML-based crack inspection methods are categorized into two main groups as artificial neural networks, ANN use or without ANN use. Conventional ML-based crack inspection methods first extract crack features using image processing, then evaluate whether or not the extracted features indicate cracks without ANN use. CNN-based crack detection approach achieves higher accuracy as it is trained to extract reliable result from the large database taken from real concrete surfaces.

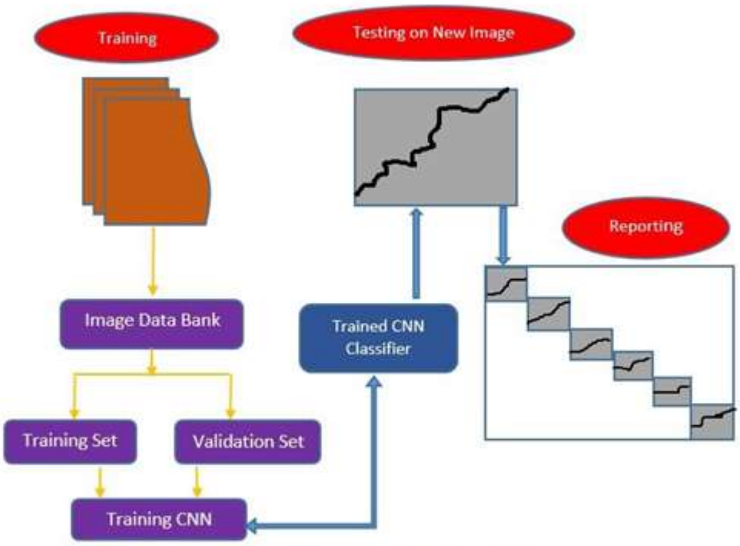

Figure 6: Machine Learning in Concrete Crack Detection

Deep learning algorithms, such as Convolutional Neural Networks CNN offer means to overcome the existing limitations in crack detection using image processing. Specifically, CNN have successfully been applied to image classification, while featuring a great level of abstraction, generalisation and learning capabilities, and a few examples can be found in. These features are key to detect damages such as cracks in concrete in a robust and reliable manner, modern CNN- based automatic crack detection system for pavements is a reliable solution to this particular issue.

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Deep learning algorithms, such as Convolutional Neural Networks CNN offer means to overcome the existing limitations in crack detection using image processing This system are key to detect damages such as cracks in concrete in a robust and reliable manner, modern CNN- based automatic crack detection system for pavements is a reliable solution to this particular issue. IP-based methods generally determine whether or not an image pixel is part of a crack region by using predefined gradient filters and a binary classifier.

Live Case Study: In Ladakh, there is one important road leading to china border in which, there crosses river shyok and there is urgent requirement of class 70 R extra wide Bailey bridge. The terrain in such areas is up to 16000 ft and deficient in oxygen in atmosphere. The temperature touches minus 30 degree centigrade and consequently snow bound areas including frozen river beds are frequently encountered. There are number of glacial deposits leading to worst environmental condition allowing hardly three to four working hours daily. In this particular case due to site remoteness, limited working period, self-sensing crack detection methodology is adopted for this bridge completed in 2019 and made functional. As the bridge is supported on group micro-piles exposed in severe harsh condition, cracks are expected to develop and to monitor the formation of cracks in foundation and above ground level, pier, abutments, deck slab pile cap etc. integrated deep learning methods in crack detection can be very useful.

Figure 7: Areal view of the Strategy Structure with automated crack detector

II. CONCLUSION:

Cracks in concrete structures is some of the most important indications or predictors for significant structural distress or damage caused by various causes such as aging. If the crack is reliably inspected, severe damage or possible failure to concrete facilities can be e effectively forecasted, and the life of the facilities can be lengthened through appropriate maintenance. Conventional crack inspections are performed by trained inspectors who visually detect cracks and then measure their length and width using suitable measuring tools, crack rulers, crack microscopes, etc. Although human-based inspection may be effective, the objectivity and reliability of the records for the cracks may easily be reduced because inspection relies on the subjectivity of the inspector. It is difficult to determine the progress of damage if the inspector changes. Thus, these drawbacks have led to extensive research on crack inspection that secures objectivity and accuracy while enabling the convenience of recording and storing data to determine the progress of damage.

This processing refers to the entire computational process of the photograph of a concrete structure; image input-output, digitization, segmentation, defect management, and defect detection. Thus, it not only detects cracks but also measures the width and orientation of the recognized cracks

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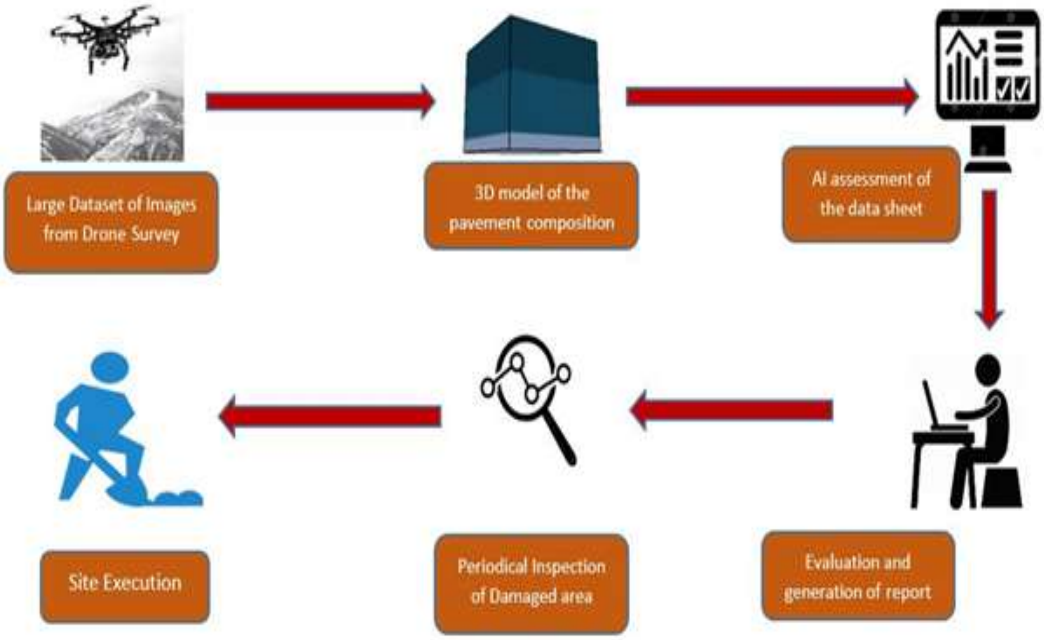

Figure 8: Process involved in Self-Sensing Concrete with induced Machine Learning

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