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A REVIEW ON – STRUCTURAL HEALTH MONITORING AND IMAGE PROCESSING

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Abstract:

This paper presents an introduction to structural health monitoring and structural damage assessment using image processing. Structural health monitoring (SHM) involves the integration of sensors, smart materials, data transmission, computational power, and processing inside the structure. SHM is the process of implementing a damage detection strategy. This process involves the observation of a structure over a period of time using periodically spaced measurements, the extraction of features from these measurements, and the analysis of these features to determine the current state of health of the structural system. One such process is using image processing, the feasibility of using image processing techniques to detect deterioration in structures has been widely investigated by many researchers in the field.

Keywords —**.Structural health monitoring, image processing, damage.**

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I. INTRODUCTION

All structures, including critical civil infrastructure facilities like bridges and highways, deteriorate with time due to various reasons including fatigue failure caused by repetitive traffic loads, effects of environmental conditions, and extreme events such as an earthquake. This requires not just routine or critical-event based inspections (such as an earthquake), but rather a means of continuous monitoring of a structure to provide an assessment of changes as a function of time and an early warning of an unsafe condition using real-time data. Thus, the health monitoring of structures has been a hot research topic of structural engineering in recent years. Structural sensing, Structural Health Monitoring (SHM), structural performance assessment and health prognosis are integral components of modern structural engineering practice.[7]

The principal objectives of the structural health monitoring are:-

i.To monitor the structural behaviour

ii.To assess structure's performance under various service loads,

iii.To detect damage or deterioration and

iv.To determine health or condition of the structure.[10]

A five-level classification (derived from Rytter's original four-level classification) of SHM activities is as follows:

Level 1: Detection - Determining if damage is present in the structure.

Level2: Localization - Locating the site of the damage.

Level3: Assessment - Estimating the amount of damage.

Level4: Prognosis - Estimating the future progress of the damage and the remaining life of the structure.

Level5: Remediation - Determining, implementing and evaluating effective remediation and repair efforts.

II. STRUCTURAL HEALTH MONITORING

Structural health monitoring (SHM) aims to assess the behavior of structures and evaluates the performance of materials during the life cycle of the structures. Such assessment should include the different parts of the structure and full assembly of the structure as a whole under different cases of loadings.

A. BRIEF HISTORY

Rail wheel tappers - used the sound of a hammer when strike against the wheel of train to detect the damage. In rotating machines, monitoring of vibration is used as performance assessment method. Then, these techniques are employed to detect the damages in the structure, besides then a new field emerged namely Structural Health Monitoring. Vibration based damage assessment of bridge structures and buildings are carried since the early 1980's [10]

B. NEED FOR SHM

- Performance enhancement of an existing structure
- Monitoring of structures affected by external factors
- Feedback loop to improve future design based on experience
- Assessment of post-earthquake structural integrity
- Decline in construction and growth in maintenance needs
- The move towards performance-based design philosophy

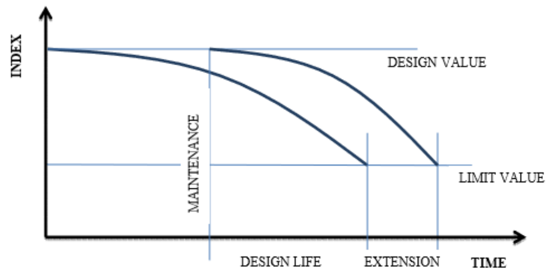

Fig **01. Typical lifetime function and the effect of maintenance [7]**

C. ADVANTAGES OF SHM

- Increased understanding of in-situ structural behaviour.
- Early damage detection.
- Assurances of structural strength and serviceability.
- Decreased down time for inspection and repair.
- Development of rational maintenance/ management strategies.
- Increased effectiveness in allocation of scarce resources.
- Enables and encourages use of new and innovative materials.

D. SHM PROCESS :

Health monitoring of civil infrastructures consists of determining by measured parameter, the location and severity of damage in buildings or bridges.

Process of SHM can be categorized under two broad classes of:-

a. Global Health Monitoring methods
b. Local Health Monitoring methods

Most of the health monitoring techniques/methods is centred on:-

i. Either finding shift in natural frequencies or
ii. Changes in structural mode shapes. [10]

SHM problem is fundamentally one of statistical pattern recognition. Therefore, the damage detection studies reviewed are summarized in the context of a statistical pattern recognition paradigm. This paradigm can be described as a four-part process:

(1) Operational Evaluation,
(2) Data Acquisition, Fusion and Cleansing,
(3)Feature Extraction and Information Condensation, and
(4) Statistical Model Development for Feature Discrimination. [4].

E. CASE STUDY

Structural Health Monitoring in recent years is used in several fields of engineering , two case studies are briefed.

1. Mahatma Gandhi Setu -The Mahatma Gandhi Bridge was constructed about 33 years ago over the Ganges River in order to connect Patna to the other side of watercourse. The bridge has 46 spans each with span length being 120m. Each span comprises of two cantilever beams on both sides which are free to move at the ends. It has two lanes one downstream and the other upstream each with a width of around 6m. Both the lanes are also free from each other and are not connected anywhere. The bridge was constructed by using 3 meter pre-casted parts being joined at both ends to complete the span. Due to heavy traffic movement and being the only bridge to cross Ganges river the bridge is used heavily now. Hence it has started vibrating with higher amplitude than it was designed for. In addition to this in many spans the cantilever beams were found to have sagged at ends. 3.2.1 The Rehabilitation Process External Pre-stressing of the bridge using 9 steel cables in a bunch (Fig 2). It was decided to pre-stress from 6 places starting from the end towards the centre portion.

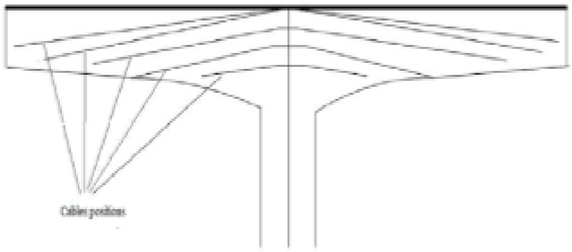

Fig. 02: The Rehabilitation using external pre- stressing using steel tendons

The task of Rehabilitation was carried out by the Freyssinet Prestressed Concrete Company (FPCC) Ltd.

When the span is externally pre-stressed by cables it causes the tip of the cantilever arms to move up with respect to the middle of the centre of span. These cables pull the arms on upward side due to the stressing done.

Deflection measurements- The variation between one side reading and the other side reading gives the deflection and comparing the deflections before and after stressing can give the effective change due to Pre-Stressing.

Temperature measurements- Temperature variations causes change in stress and deflection in the cantilever arms also vary. Temperature sensors are installed at the inside and outside surface of the bridge. Maximum value of strain change due to pre-stressing obtained is 70 $\mu\varepsilon$ and average maximum deflection recovery values have been recorded as 24mm. These values were much lower than theoretical estimates. [10]

2. DUBAI- monitoring of world's tallest building BURJ KHALIFA TOWER. It is 828m tall with more than 160 stories. Construction period - 2004-2010

Temporary real time monitoring - After earthquake in Iran on 9th September, 2008.

Permanent full scale real time monitoring - After earthquake in Iran on 20th July, 2010.

There are many sensors installed at different stories with their own significance such as:- 3 pairs of accelerometers at foundation to record base acceleration, 6 pairs of accelerometers at level 73, 123, 155 on the top of concrete and 10M3, Tier

23A on the top of pinnacle to record the tower acceleration simultaneously at all levels.
There is a GPS system installed at level 160 M3 to capture the building displacement, 23 sonimeters in all terrace and setback levels to measure wind speed and directions.
A weather station at level 160M3 to measure wind speed and direction, relative humidity and temperature, there are sensors to capture building frequencies, damping ratio at low amplitude due to both wind and seismic events.
Time history is also recorded at the base of the tower due to seismic events. [11]

III.IMAGE PROCESSING

Automated health monitoring and maintenance of civil infrastructure systems is an active yet challenging area of research. Identifying appropriate applications for technology to assess the health and safety of structures is an important issue around the world. For example, current infrastructure inspection standards require an inspector to travel to a target structure site and visually assess the structure's condition. A less time-consuming and inexpensive alternative to current monitoring methods is to use a robotic system that could inspect structures more frequently, and perform autonomous damage detection. Among several possible techniques is the use of optical instrumentation (e.g., digital cameras). The feasibility of using image processing techniques to detect deterioration in structures has been widely investigated by many researchers in the field. Traditionally, structure conditions have been monitored through visual inspection methods with structural deficiencies being manually identified and classified by qualified engineers and inspectors. More advanced and objective bridge inspections are required for monitoring long-term bridge performance The stages of increasing difficulty that require the knowledge of previous stages, namely:

1) Detecting the existence of the damage on the infrastructure
2) Locating the damage
3) Identifying the types of damage
4) Quantifying the severity of the damage [2]

F. The main advantages of digital image processing

1. Enhancing the edges of an image to make it appear sharper; an example can be seen in fig 3. By inspection, the second image appears cleaner. It is a more pleasant image. Sharpening edges is a vital component of printing: in order for an image to appear at its best on the printed page some sharpening is usually performed.

Fig 3: Sharpening of an image

2. Removing noise from an image, noise being random errors in the image. An example can be seen in fig 4 . Noise is a very common problem in data transmission: all sorts of electronic components may affect data passing through them, and the results may be undesirable.

Fig 4: Removing noise from an image

3. Removing motion blur from an image. An example is seen in fig 5. Motion blur may occur when the shutter speed of the camera is too long for the speed of the object. In photographs of fast moving objects: athletes, vehicles for example, the problem of blur may be considerable

Fig 5: De-blurring an image

4. Obtaining the edges of an image. This may be necessary for the measurement of objects in an image; an example is shown in fig 6. Once we have the edges we can measure their spread, and the area contained within them. We can also use edge detection algorithms as a first step in edge enhancement.

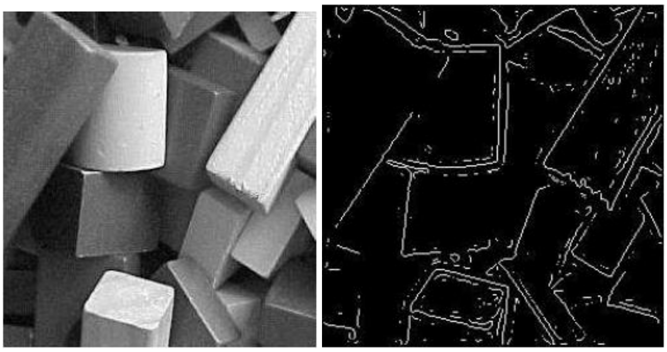

Fig 6: Finding edges in an image

5. Removing detail from an image. For measurement or counting purposes, we may not be interested inall the details in an image. For example, a machine inspected items on an assembly line, the only matters of interest may be shape, size or colour. For such cases, we might want to simplify the image. Fig 7 shows an example: in image (a) is a picture of a buffalo, and image (b) shows a blurred version in which extraneous detail

Fig 7: Finding edges in an image

G. IMAGE PROCESSING TASK

The various stages in performing an image processing task on a given image and the method of accomplishing them is explained as below:

Acquiring the image: First step is to produce a digital image of the object of interest. This can be done using either a CCD camera, or a scanner.

Pre-processing: This is the step taken before the major image processing task. The problem here is to perform some basic tasks in order to render the resulting image more suitable for the job to follow. In this case it may involve enhancing the contrast, removing noise, or identifying regions likely to contain the area of interest to be studied.

Segmentation: Here is where we actually get the object; in other words we extract from the image that part of it which contains just the beam or other things which has to be studied.

Representation and description: These terms refer to extracting the particular features which allow differentiating between objects. Here one will be looking for curves, holes and corners which facilitate the comparison of the different digits.

Recognition and interpretation: This means assigning labels to objects based on their descriptors (from the previous step), and assigning meanings to those labels.

IV. CURRENT SCENARIOS OF IMAGE PROCESSING APPLICATION FOR SHM

The sustainability of the civil infrastructures may be achieved by the periodic assessment that needs effective SHM tools and techniques. The conventional methods of SHM are quite time consuming and laborious. Especially, in case multi span bridges, elevated buildings, monuments, etc. the conventional methods are not quite effective for rapid full-field monitoring and hence, the image processing method can be used.

Yue et al. (1996) performed the digital image processing technique in asphalt concrete to study the orientation of coarse aggregate particles. It was assumed that the concrete mixture is homogeneous and isotropic. This research concluded that the specimen compacted with gyratory compactor have the orientation to lie horizontally while the specimen compacted with Marshall Compactor have random orientation.[12]

A study was conducted on image processing based damage detection of offshore infrastructure elements using textural information by O'Broyne et al. (2012). In this research, textural analysis based image segmentation Support Vector Machine (SVM) classification for detecting and quantifying the damage regions was used. The subject of the research considered was three images a corroded metallic surface in marine environment. To study the texture analysis, Grey-Level COoccurrence Matrix was evaluated by the author. The author concluded that this analysis was able to detect the seven textures, namely; contrast, correlation, homogeneity, skewness, angular second moment, entropy and kurtosis. These textures could be able to detect whether the structure is being damaged or not. [9]

As per the research carried by McCarthy et al. (2013), Image de-blurring technique was used to monitor the dynamic structural testing. This research was considered to be the new approach towards the measurements of vibration envelope. The whole vibration interval was measured through high resolution blurred image without any need for high-speed imaging. The results of this research were presented for a series of small scale laboratory models and large scale test. [6]

A demonstrated model was prepared to monitor the health of civil infrastructures which involves the effective use of Unmanned Aerial Vehicles (UAVs). Sankarasriniwasin et al. (2015) integrated the UAVs , image processing and data acquisition to assess the surface degradation. A MATLAB Graphical User Interface (GUI) was developed to perform the analysis between real and acquired images. This research concluded that the demonstrative model was feasible & reliable for health monitoring of civil infrastructures.

An experimental approach was Erhart et al. (2015). The author considered art image assisted total station (IATS) and passive target markings. To measure the distance, a laser distance measurement unit was integrated with the total station. This experiment was primarily performed in the laboratory and the field. The laboratory experiments showed that movements can be easily detected even for very small distance of 0.2mm for single frames. During the field experiment, life-size footbridge was considered. It concluded that the frequencies of structural oscillations were easily identified. [3]

Nhat-Duc Hoang(2018) study establishes an intelligent model based on image processing techniques for automatic crack recognition and analyses. In this new model, a gray intensity adjustment method, called Min-Max Gray Level Discrimination (M2GLD), is proposed to preprocess the image thresholded by the Otsu method. The goal of this gray intensity adjustment method is to meliorate the accuracy of the crack detection results. Experimental results point out that the integration of M2GLD and the Otsu method, followed by other shape analysis algorithms, can successfully detect crack defects in digital images.[8]

V. CHALLENGES-

Although the opportunities of image processing for the structural health monitoring offers significant benefits but there are certain challenges towards this technique. To yield the quality damage detection and quantification, several contextual parameters such as types of damage, preliminary parameters for image analysis are needed. If these parameters are not available, certain significant challenges in terms of structural damage patterns will be encountered. Moreover, complexity of image contents is the other challenge that can be faced during its implementation. Limited memory of the digital camera will add difficulties for continuous SHM as it is very difficult to send and receive data continuously in a massive network. Securities issues may be considered as one of challenge as there is no surety about the data sent that could have compromised, modifies or denied. The software issues can be taken into account for the real time applications. [2]

VI. CONCLUSIONS

The concept of SHM is matured and considered as the one of the prime technology to ensure the health monitoring of various structures. Being popular in other field, digital image processing techniques have attained little attention in the field of SHM. Image-based monitoring has proven its application in the past to monitoring structures. The various advantages include: measurement can be made without contact with the structure, making it suitable for difficult measuring tasks where there is no stable support for displacement gauges. A very high number of points can be measured by a single camera sensor, limited only by sensor resolution, allowing monitoring of complex deformation patterns. Multiple camera sensors can monitor deformation in three dimensions.

While the most accurate measurement work still requires targets to be fixed to structures, digital image correlation (DIC) makes possible measurement of structures without targets fitted, provided their surface has sufficient natural texture. The scalability of image processing means measurements of large structures are possible to sub millimeter accuracy while the accuracy of measuring small scale laboratory tests can be in the order of microns.

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