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DYNAMIC STRUCTURAL ANALYSIS USING SPATIAL DATA MONITORED BY 3-D LASER SCANNER

Sunaryo SUMITRO
Smart Structures LLC, USA

Hiroshi MATSUDA
Nagasaki University, Japan

Yukihiro ITOH
Saga University, Japan

Takuji OKAMOTO
Keisoku Research Consultant Hiroshima, Japan

Abstract

3-D Laser Scanner measurement technique which is categorized as one of Full Field Optical Stress & Strain Measurement (FFOSSM) technology, enables monitoring of shape and dimension of measured-objects in non-contact, remotely and globally. In order to provide a rational structural health monitoring-based maintenance (SHMBM) strategy, it is important to assess current structural properties of existing structures due to long-term structural degradation effects. However, they mostly lack sufficient information of their spatial shapes and dimensions. In this paper, the applications of 3-D Laser Scanner and digitalized camera in capturing 3-D spatial coordinate of shape-complicated existing structures are reviewed, and their contributions to structural health monitoring are discussed. Captured spatial data was converted into surface data and solid data to perform three dimensional finite elements for dynamic structural analyses. As the result, it is validated that integration with a post-processing system such as a structural analysis system, enables current structural performance information of existing structures in a long term structural health monitoring scheme to be provided.

INTRODUCTION

Photogrammetry is a measurement technology, in which the three-dimensional coordinates of points on an object are determined by measurements made in two or more photographic images taken from different positions. 3D scanner is a device that analyzes a real-world object or environment to collect data on its shape and possibly color. The collected data can then be used to construct digital, three dimensional models that are used in a wide variety of applications. By taking its capability in monitoring the shape and dimension of measured-objects in non-contact, remotely and globally, devices are used extensively in landscaping simulation during the structural design stage, bridge load test, and structural health monitoring-based maintenance (SHMBM) purposes[1,3].

The degradation information related to structural health monitoring-based maintenance (SHMBM) such as, crack propagation, delamination of concrete layer, carbonation, saltination, stress, flexure, displacement and vibration characteristic at either surface or inner of a existing structure, can be explored by full field optical measurement devises, e.g., infra-red, ultra-sonic wave, elastic-wave, laser, electromagnetic wave, and magnetic wave. The output information can be stress and/or other visible parameters in remote and non-contact media as shown in Fig. 1[4,5,6].

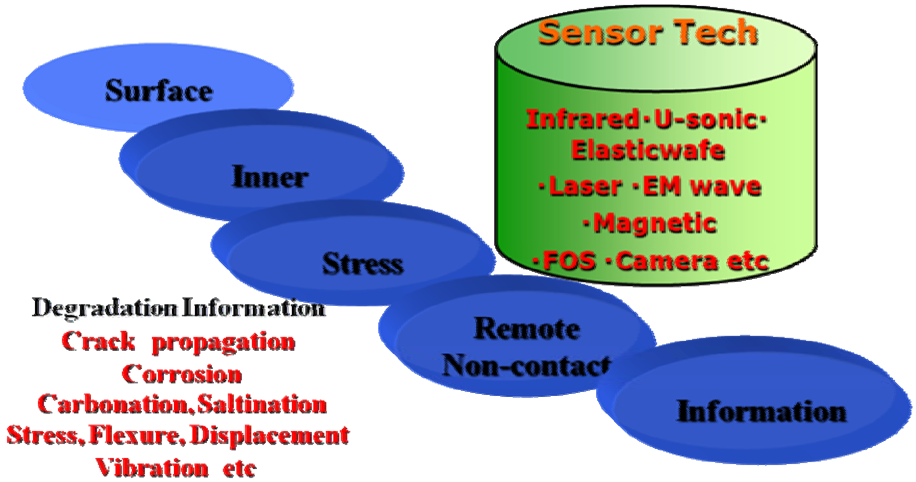


Fig. 1. Structural health monitoring information

Concerning infrastructure assets, it is important to assess current structural properties of existing structures due to long-term structural degradation effects. However, it is troublesome to find simple method to assess their current structural performances, even though most of them lack of their design documentation that describes their spatial shapes and dimensions. Therefore, a scheme of system that can capture the existing structures and save into the archive, easy to access, and up-gradable is significantly necessary. In response to this need, an integrated structural analyzer system has been developed by interfacing full field optical monitoring devices with extendable monitoring data and post analyzing processors [9,10]. This system enables to the conduction of structure analyses (static or dynamic analyses) to assess the current performance of existing structures. Furthermore, future continual degradation parameters can be updated into the system conveniently, and fractural-based structural analysis systems can be also approached.

As one of the application examples here, the shape and spatial information of a warped plate was captured by a 3D Laser Scanner and a digitalized camera. To verify its measurement accuracy, those analyzed dimensions were compared to measured data. Then, those captured spatial data were converted into surface data and solid data to perform three dimensional finite elements for dynamic structural analyses [1,2]. Then, the analyzed mode shapes and their natural frequencies were compared with Holography interference method. By investigating good agreement among the results, it is confirmed that this integrated structural analyzer system is reliable to provide structural information for planning a sustainable maintenance strategy.

DATA PROCESSING

Computerized data processing from a shape's spatial coordinate measurement to geometrical model can be summarized as: (i) Point-wise spatial model; (ii) Wire-frame model; (iii) Surface model and (iv) Solid model.

Spatial Coordinate

The shape of a captured object is stored as 3D coordinates spatial data. Then, 3D coordinates of the entire surface of the specimen are precisely calculated and divided into the same range. The results are the 3D shape of the component at the 3D point-wise model as shown in Fig. 2(a).

Wire Frame Model

A wire frame model is a visual presentation of an electronic representation of a three dimensional or physical object used in 3D computer graphics. It is created by specifying each edge of the physical object where two mathematically continuous smooth surfaces meet, or by connecting an object's constituent vertices using straight lines or curves. The object is projected onto the computer screen by drawing lines at the location of each edge as shown in Fig. 2(b).

Surface Model

A surface model is used in CAD and other computer graphics processing software to describe the skin of a 3D geometric element. The wire frame at the surface of a captured object will be combined to create a surface model as shown in fig. 2(c).

When defining a form, an important factor is the continuity between surfaces. It affects how smoothly they connect to one another. The continuity is defined using the terms: G0 for position (touching); G1 for tangent (angle); G2 for curvature (radius) and G3 for acceleration (rate of change of curvature), respectively.

Solid Model

A solid model is the unambiguous representation of the solid parts of an object, that is, models of solid objects suitable for computer processing. It is also known as volume modeling. (see Fig. 2(e))

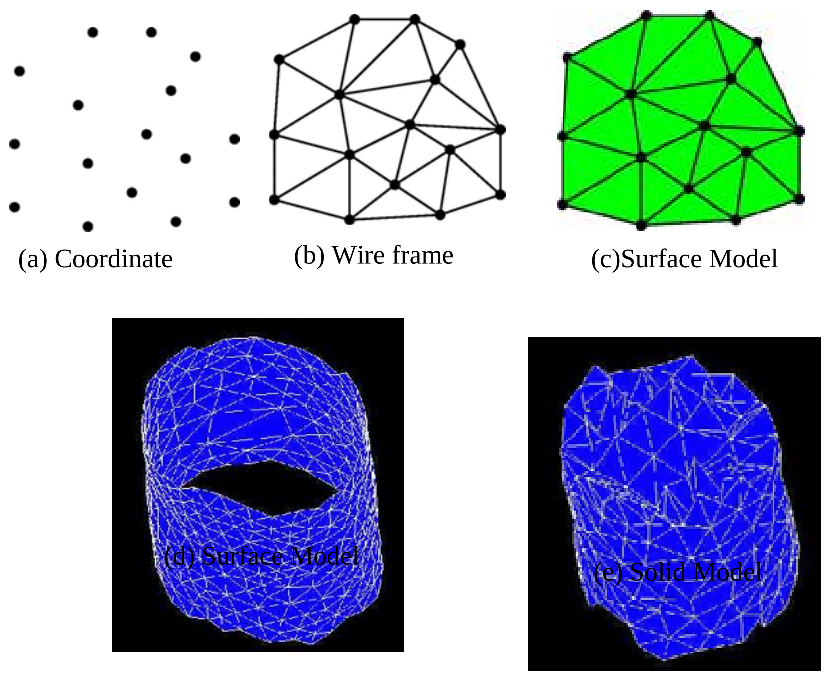


Fig. 2. Geometry Model

MODEL VERIFICATION

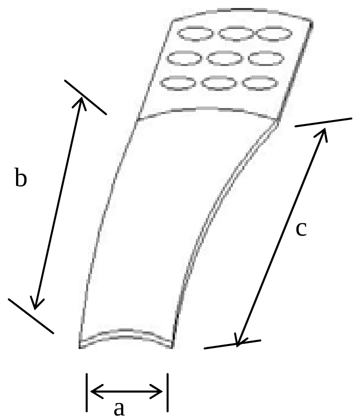
Model verification tests were performed to validate photonic measurement data.

Dynamic Structural Analysis of a Warped Plate

Verification of measurement precision of 3D photogrammetry and analytical precision of dynamic structural analysis was performed by using a warped plate as shown in Fig. 3(a). The material properties were shown in Table 1.

Three dimensional side length of the warped plate were measured as shown in Fig. 3(b), and compared to the analyzed values. As a result, as shown in Table 2, it is confirmed that the measurement was done at high precision at three places entirely.

(a) Photogrammetry



(b) Measured

Fig. 3. Warped plate

Table-1 Material Properties

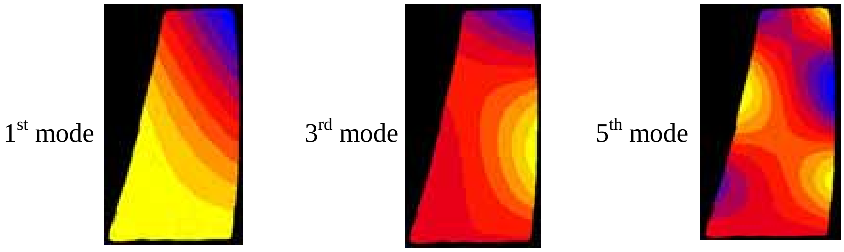
Young Modulus	Poisson Ratio	Density
71GPa	0.33	2.7g/cm^2

Table-2 Measured vs Analyzed -Length Comparison

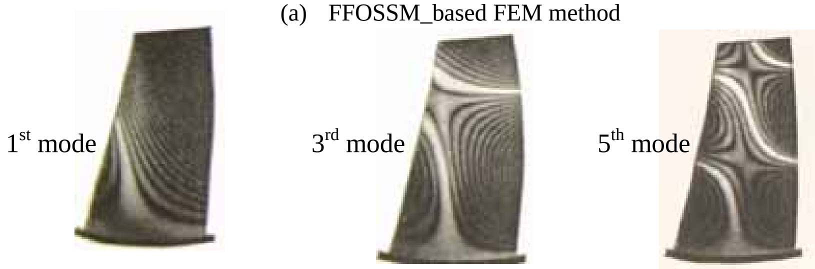
	a	b	c
Measured [mm]	43.8 (100%)	155.5 (100%)	155.5 (100%)
Analyzed [mm]	43.7 (99%)	155.3 (99%)	155.5 (100%)

A finite element model was generated from the measurement data, and the dynamic structural analysis was performed by using the generic finite element method (FEM) program. Three nodal shell elements were used to perform the FE model. Furthermore, the analytical natural frequencies were verified by the modal measurement by holography interference method. As the result, they have good agreements in their dynamic mode shape and natural frequencies for each measured modal as shown in Fig. 4 and Fig.5, respectively.

By considering the above comparison, it is confirmed that photogrammetry can be integrated with a post-processing system such as structural analysis system, to provide sufficient current structural performance information of existing structures.



(a) FFOSSM_based FEM method



(b) Holography interference method

Fig. 4. Mode shape comparison

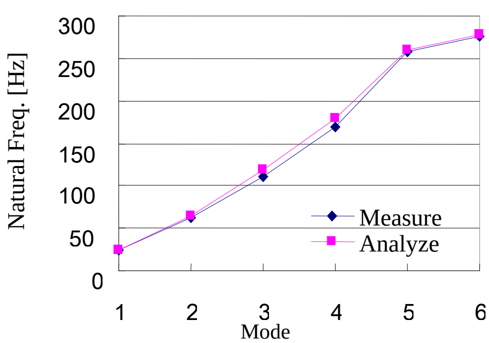


Fig. 5. Natural frequencies comparison

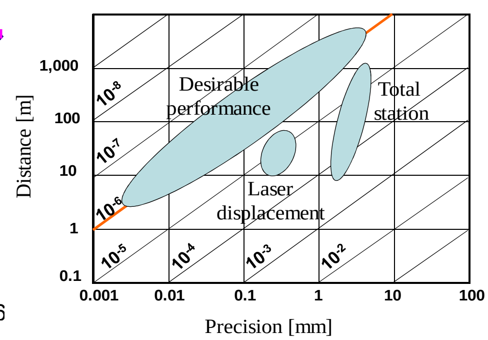


Fig. 6. SHM device performance

The capability and advantages of the 3D scanner system was confirmed through a large scope of field applicationsfrom bridges tunnels dams coastal structures, harbors airports, and structures to highrise buildings[1,2].

Fig. 6 shows the relationship between the resolution S and remotely distance of L. Nowadays, it enables to achieve S/L better 10^{-6}, in other words "Precision of 0.1mm can be monitored in a distance of 100m". Additionally, by minimizing the influences of environmental effects, the durability, capability and performance in long term structural health monitoring is getting improved. Therefore, optical base sensing technology is a promising device to provide necessary data for interpretation, appraisal and applications of life cycle cost assessment on civil infrastructures.

CONTRIBUTION TO STRUCTURAL HEALTH MONITORING

Proposed SHMBM Scheme

To provide supporting information for a reliable maintenance, it is important to assess current structural performance. Most of the infrastructures, even, lost their archive drawings. Therefore, by applying full field optical measurement, a structural health monitoring-based maintenance scheme is proposed and its schematic description is shown in Fig. 7:

(i) Conduct initial structural information such as shape and dimension by utilizing 3D Laser Scanner;

(ii) Capture visible structural degradation factor such as crack distribution by total station or other possible optical measurement device and create a data base for current structural degradation condition;

(iii) Perform structural analyses to assess its current structural performance;

(iv) Monitor their degradation condition periodically such as crack propagation, and update to the crack distribution data base; and

(v) Execute structure analyses of the deteriorated structures based on fracture mechanics approach.

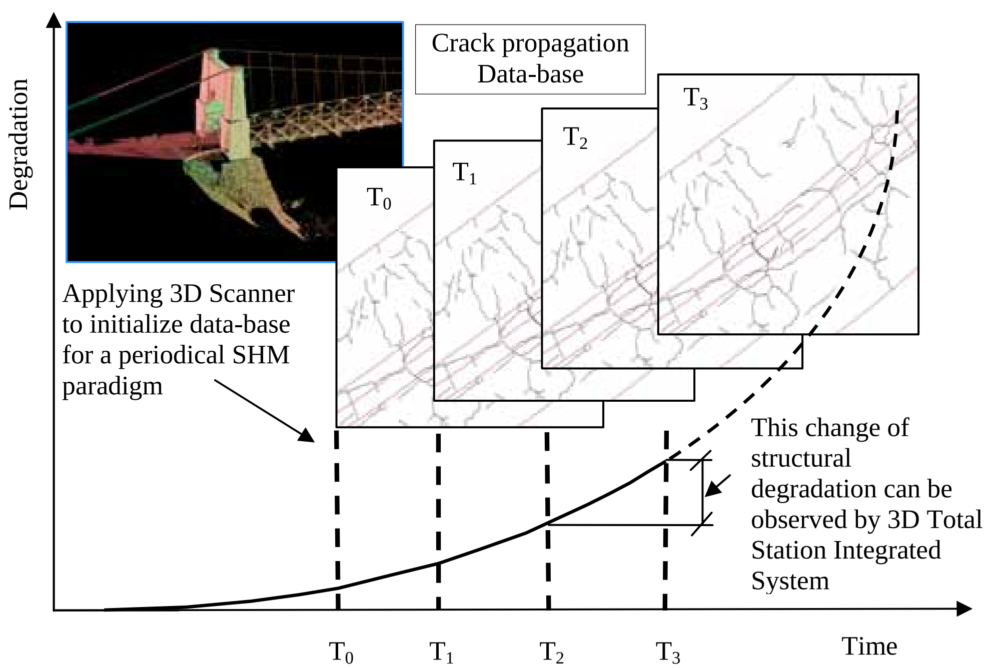


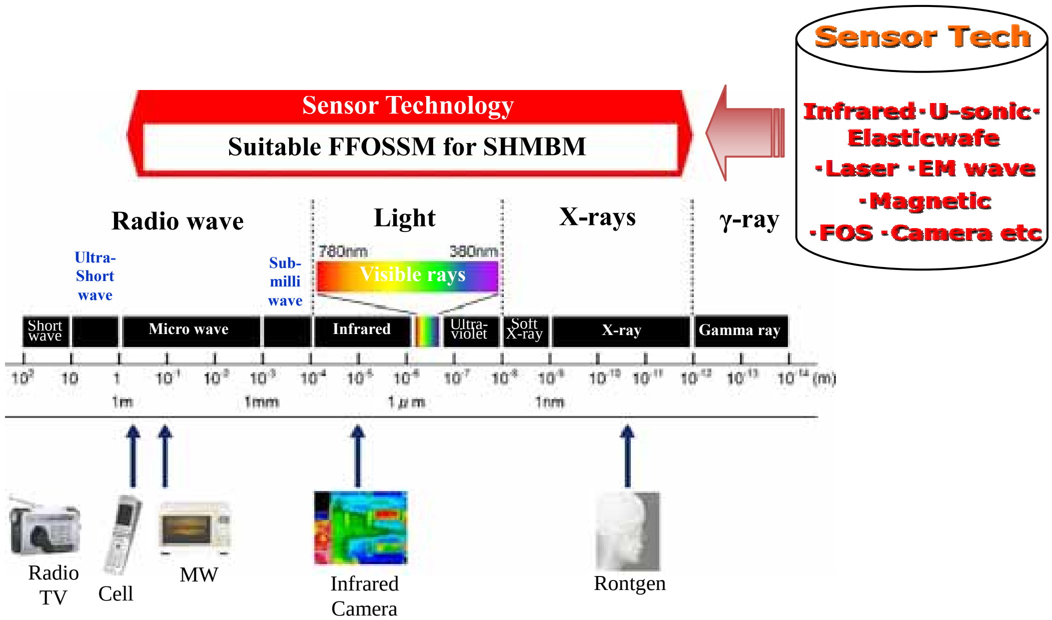
Fig. 7. Proposed SHMBM Scheme

FFOSSM Features

The features of FFOSSM in structural health monitoring-based maintenance (SHMBM) contribution, such as, (i)safe and save non-contact monitoring: scaffold, attachment and cabling are not necessary; (ii)short time and huge information: different from Point by Point measurement technique, FFOSSM provides not pointless, but plane and spatial information; and (iii)high resolution in a wide range of measurement : enable to grasp planar information globally.

Structural Information for Existing Infrastructures

Due to human memory limitation, job position transformation, imperfection, and inability to provide a reliable monitoring system can lead to overly optimistic reports on structural health. Therefore, a 3D Scanner Integrated System that enables to provide structural information for existing infrastructures is needed to provide supporting consideration for a reliable maintenance strategy. Conditional information for existing infrastructures along their life cycles, e.g., Dimension, Mechanical behavior, Diagnostic and Evaluation, Repair and Retrofit, Design and construction, and Geotechnical properties, can be monitored and save in a timely accessible archive by optical measurement device in the wave length as shown in Fig. 8.



CONCLUDING REMARKS

The concluding remarks can be summarized as follows:

1. The integrated 3D Laser Scanner System with a structural analysis post-processing program enables to provide current structural performance information of existing structures in a long term structural health monitoring scheme.
2. The deteriorated structural information and conditional information during a life cycle of an as-constructed structure can be documented, updated and accessed timely.
3. Human memory limitation, job position transformation, imperfection and inability to provide a reliable monitoring system can lead to overly optimistic reports on structural health.
4. The proposed structural health monitoring-based scheme provides valuable information for directing timely maintenance relief to those areas of the structure most in need of repair, so the following items can be achieved:
   (1) Planned repair or replacement of the structure before catastrophic collapse;
   (2) Improved allocation of scarce maintenance funding for the highest at risk structure member;
   (3) Determination of structural health after catastrophic hazard events, such as, earthquake, typhoon, fire, and explosions.

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