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Optimal finite element model with response surface methodology for concrete structures based on Terrestrial Laser Scanning technology

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ABSTRACT

Terrestrial Laser Scanning (TLS) technology, which is hailed as another technological revolution in the field of surveying and mapping, is well known as a structural deformation monitoring device for concrete structures. In the current paper, we frame the finite element model (FEM) of concrete structure based on three-dimensional TLS technology and optimize the model by response surface methodology (RSM). It is theorized and confirmed that volume-based FEM model will be more precise than the displacement-based model, due to that the distortion of specimen is considered with the benefit from volumetric analysis when composite structures is distorted with loads.

1. Introduction

Terrestrial Laser Scanning (TLS) measurement is a reliable method and a promising way to gain 3D point clouds and intensive information of object surfaces. It was hailed as another technological revolution in the field of surveying and mapping after GPS technology.

1.1. Surface-based TLS measurements

Surface-based TLS measurements have been adopted in lots of paper. Some authors convert point clouds into a mesh or consistent polygonal, such as in [1], in which mesh surface includes edges and faces. Planes which are fitted to point clouds are applied by Tsakiri et al. [2] when estimating the deformation of structures. The plane model is appropriate for small regions and therefore the segment was divided into raster cells. In a tunnel monitoring, Van Gosliga et al. [3] modeling the tunnel with a cylinder.The geometric model, coordinate transformation and genetic algorithm are chosen and applied to the cylinder fitting calculation. Three kinds of cylindrical surface fittings are compared to meet the engineering demand. Other researches focus on free form curve and surface approximation. Hyungjun Park [4] expands the idea of B-spline curve fitting, and proposes a new approach to B-spline surface fitting to rectangular grid points, which is based on adaptive knot placement using dominant columns along u- and v-directions. Alexandre Boulch etc. [5] presents a new method for estimating normal on unorganized point clouds that preserves sharp features. It is based on a robust version of the Randomized Hough Transform. Djordje Brujic etc. [6] present a method for realizing improvements in the computational efficiency of fast and accurate fitting of non-uniform rational B-spline. The basic idea is that the sparsity structures of the relevant matrices that are specific to the problem of NURBS fitting can be precisely defined and that full exploitation of these structures leads to significant savings in both computational and storage requirements.There are many devices and techniques for gaining three dimensional information in recent years [7–13]. Several studies have analyzed the behavior of these instruments [14–19].

1.2. Response surface methodology

Conventional FEM model updating takes lots of time and brings in complicated calculation when repetitively adjust the FEM model, even worse when it is involved in complex structures. So it is not favorable for practical engineering application [20]. Aiming at the serviceability assessment, Luca Sgambi etc. [21] propose and apply a method based on the combined application of genetic algorithms and a finite element method investigation. T. Marwala adopts particle-swarm-optimization method for finite element model updating, and this method is tested on a simple beam and an unsymmetrical H-shaped structure [22]. It is observed that, on average, this method gives a more accurately updated finite-element model than the genetic-algorithm method does. B. Echard etc. [23] propose an iterative approach based on Monte Carlo

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Simulation and Kriging *meta*-model to assess the reliability of structures in a more efficient way. However, to assess reliability, the most popular approach remains the numerous variants of response surfaces [24].

1.3. Work-flow

In the current paper we updating the finite element model (FEM) of reinforced composites concrete beams base on three-dimensional Terrestrial Laser Scanning technology and optimize the FEM model by the response surface methodology. The work flow of updating the FEM model by the RSM is presented in Fig. 1.

The process of FEM updating based on RSM model dominantly includes several steps. (1) Determine the design space which requires to define the value range of the parameters to be updated. (2) Select the parameters. The parameters which make significant influence to the response value, where it is volume V in this paper, are selected. (3) Fix the order and number of points of RSM model. Here we take advantage of polynomial functions to describe the relationship between the response variable and the design variable. When the order is set to 5, it stands for a fifth- order polynomial function. The higher the order is, the more accuracy can be achieved. The number of points is the number of test points which are chosen within the design space to estimate the function coefficients. Similarly, with a larger number of points, we can obtain higher accuracy of the estimated results, however, in this way, more times of FEM computing is required. (4) Build function model. With the determined order and number of points, we can construct a RSM function model. (5) Calculate test design. Making use of the FEM model, we simulate the FEM results of each test points. (6) Approximate the coefficients of function. With the design points and FEM results, we take advantage of RSM model from step 4 to estimate the coefficients of the function. (7) Check the RSM model. After all the steps above, we check the accuracy of RSM model. The criteria is determination coefficientR^2 which is calculated in formula (2). When R^2 is on the verge of value 1, the accuracy of RSM model is significant and acceptable, then the RSM model will be out putted, if not, we will increase the order and number of test points of RSM model and repeat steps 3–7.

2. Experiment

This measurement is built to investigate concrete structural characterization.The concrete beams for experiment are shown in Fig. 2.

The load increment is selected at 4 kN at first till the appearance of the first crack. Then the load increment is set to 5 kN. Every load step lasts 5 min. The load jack is seen in Fig. 3.

Fig. 2. The concrete beams for experiment.

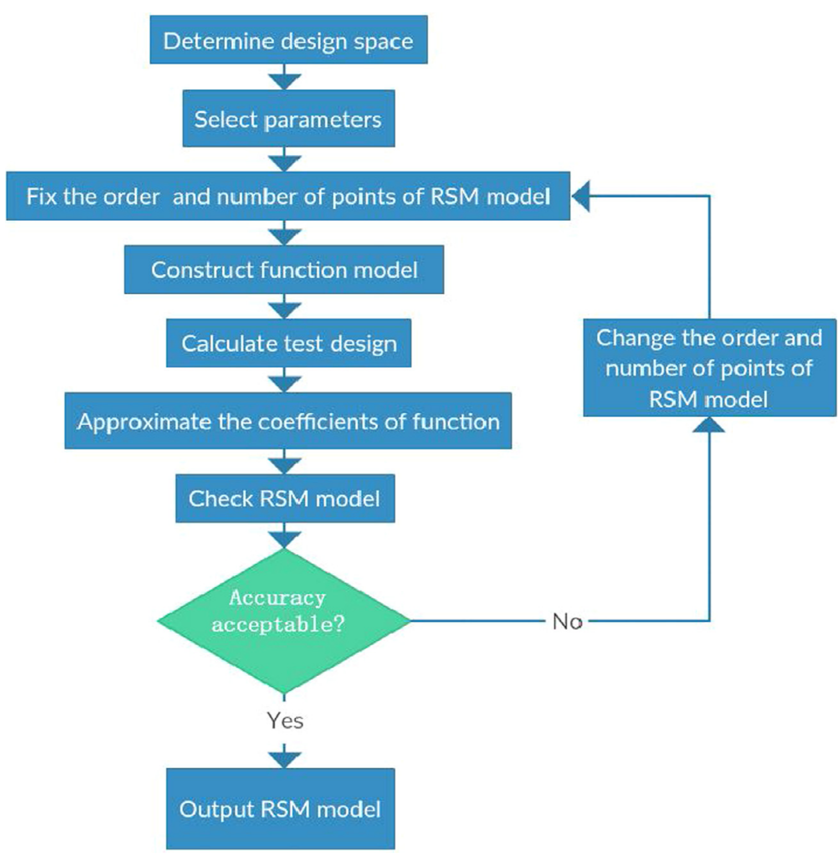

Fig. 1. Work flow of RSM optimal model.

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