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Terrestrial laser scanning technology for deformation monitoring and surface modeling of arch structures

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ABSTRACT

Terrestrial laser scanning (TLS) is capable to be a reliable deformation monitoring device with high-precision for concrete composite structures. Measurements based on TLS for an arch structure with monotonic loading is carried out. In this paper, comparison between original and optimized extraction of point clouds are presented. Surface approximation is implemented, where the vacant measurement area is also covered and the uncertainties of different-order surfaces are investigated. The results of surface approximation based on TLS measurement have certain relation with surface roughness of specimen, which will be eliminated by subtraction in deformation calculation.

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1. Introduction

Terrestrial laser scanning (TLS) is capable to be a reliable deformation monitoring device with high-precision for composite structures. Since reinforced concrete (RC) and brick structures are regularly required to satisfy the high demands of comfort and security, they have been ubiquitous building materials and diffusely applied in various types of engineering structures. As a result, it is essential to monitor the deformation and assess safety of these structures against failure. And the prediction of the load-displacement behavior of the structures throughout the range of elastic and inelastic response is desirable [1–3].

1.1. Background

Measurement data can be acquired continuously or at specific time intervals during the lifetime of a structure and combined with damage detection routines. Various devices for acquiring 3D information have been applied in recent years and several studies have analysed the behaviour of these instruments [4–6]. Comparing with other devices for deformation measurement, one significant advantage of the TLS is that it has fewer requirements in experimental environment, and can easily be implemented with a simple experimental setup [7–8]. As terrestrial laser scanners have become more available, their applications have become more widespread, creating a demand for affordable, efficient and user-friendly devices [9].

Main principles of various TLS instruments are time-shifting, triangulation, and phase difference during the propagation of laser [10], where the currently used Z + F IMAGER 5006 is the third kind one. With the benefit of high-accurate measurement of distance and angles, 3D coordinates of grid points on object surface are obtained. Intensity of reflected laser, color, time, position, etc. can be additional data from TLS scanner. All the data are possible to be stored permanently and readable easily.

1.2. State of the art

Our work of deformation monitoring concerns two main parts: the first part is related to data extraction and segmentation, the second part is about surface approximation. Hybrid segmentation in both 3D object space and 3D image space (i.e. grayscale or RGB image) is proposed in [11]. Segmentation starts in object space by applying surface growing based on updating plane parameters and robust least squares plane fitting. Consequently, segmented results from object space is utilized to perform regional growing segmentation in image space to extract object boundaries more accurately.

Drawback of the proposed approach is that segmentation in the object and image spaces are not performed simultaneously. Thus, similarity of intensity values in image space will lead to under-segmentation. Superpixels algorithm avoids under-segmentation by reducing image complexity through pixel grouping [12]. It is

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based on voxel relations and takes advantages of spatial and color information of the object to produce over-segmentations results [11]. It is quite fast and has better performance in object boundary extraction comparing to other existing segmentation approaches. In this research, supervoxels segmentation benefits from both computed normal vectors of the point clouds and its reflectivity values as spatial and color information respectively.

Surface approximation from point clouds is popular in many fields, e.g. shape processing, rendering tasks [13], reverse engineering, etc. New attempt has been made in structural analysis with combination to physical models [14]. The salient benefits mainly lie in outlier removal, surface inspection, and piece wise instead of point wise record.

1.3. Motivation

In current experiment, an arch-shape construction made of concrete and brick material is investigated with multi-sensor system. The arch was set on the first floor while TLS scanner on the second floor for the purpose of the most scanning area of the specimen. After epoch measurements and data collection, point clouds extraction is carried out based on TLS data aiming at the isolation of top surface of the arch. Optimization of the extracted point clouds are processed thereafter by polygonal selection in Cloud Compare software.

These pre-steps offer point clouds exactly of the arch top surface and discarding the surrounding objects. Challenge in deformation analysis of the overall top surface of the arch is that vacant measurements is unavoidable in the experiment, for the reason that a series of steel beams on top of the specimen interrupted the views from the laser scanner. To solve this problem, parametric polynomial surface is proposed with elaborate discussion of uncertainties. Deformation referring to the complete arch area is computed based on that.

2. Experiment

The loading process is shown in Table 1, where each load interval is carried out with constant load speed. In between each load interval, there is a non-load period of 10 min, when the measurements are performed.

The emplacement of devices is shown in Fig. 1, where instruments are mainly classified for TLS Z + F IMAGER 5006 (the upper left), one Leica Laser tracker (the lower right) and one Nikon camera (the lower middle). Two extra cameras stood on both sides of Nikon camera, which are set by another institute to monitor the side surface of the arch.

The span of arch is 2 m and thickness is 10 mm. In this research, top surface of the arch is of utmost interest for deformation monitoring since it is under load pressure in 13 epochs and has significant deviations comparing to the other parts of object. In the future work, frontal part of object is taken into account for more precise deformation analysis.

Targets of TLS are set on stable platform on both sides for the possibility of data calibration. Some circular targets are attached to the stable platform on the left side of the arch and some are to the bottom of the arch (black circles in Fig. 2) for camera measurement. Utilizing camera would assist us to obtain feature points with high resolution since discrete feature point extraction is an advantage of camera [15]. In addition, 11 magnetic holders (red circles in Fig. 2) mounted on top of the arch, steel beams and surroundings are measured by laser tracker, which is an accurate sensor system with maximum permissible error of 15 μm + 6 μm/m, which provides this possibility to compare with processed TLS data in the future.

Table 1
Load steps of the arch experiment.

Steps	Load range	Load speed
1	0–12 mm	0.002 mm/s
2	12–14 mm	0.003 mm/s
3	14–20 mm	0.004 mm/s

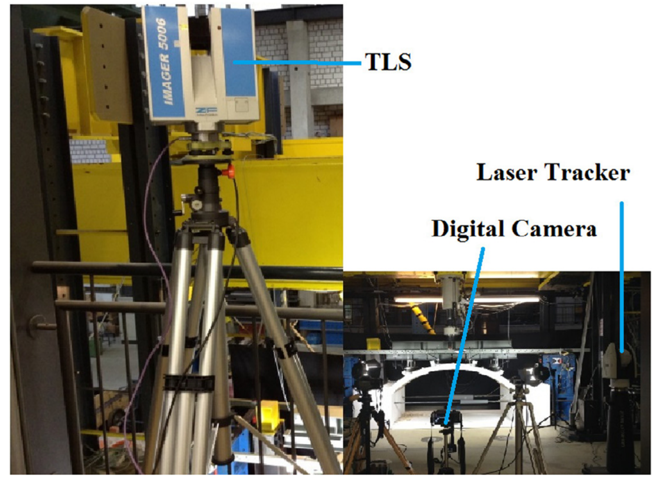

Fig. 1. The experiment set up.

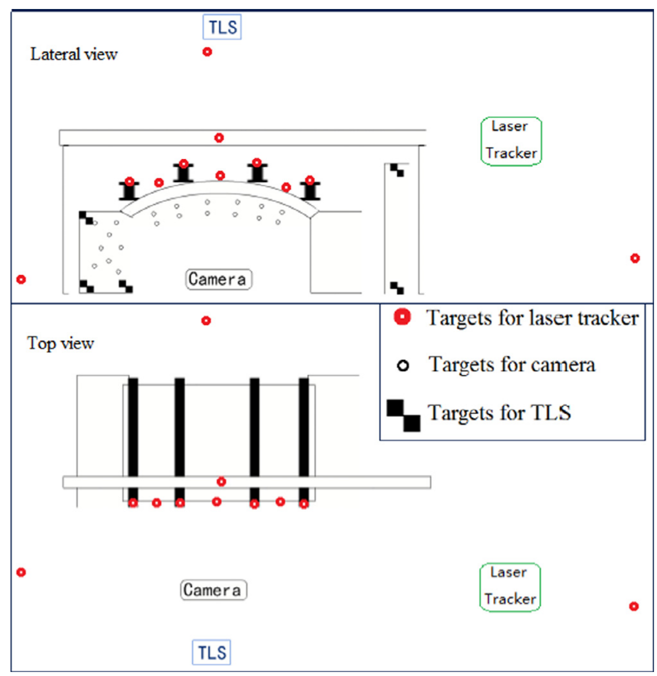

Fig. 2. Sketch of instruments in the measurement.

3. Data extraction

The arch is occluded with some other objects (e.g. beams and so on) and needs to be separated that enables us to perform surface approximation more accurately. Work flow of data extraction is presented in Fig. 3.

With raw TLS point clouds data, reflectance image is generated from intensity value. Thresholding and filtering is performed

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