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Quantification of edge loss of laser scanned data at spatial discontinuities

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ABSTRACT

Laser scanning is a promising geometric data collection tool for construction, facility, and infrastructure management due to its fast sampling rate (tens of thousands of measurements per second) and millimeter-level accuracy. However, laser scanned data contains inaccurate data points at spatial discontinuities (object edges). These inaccurate points, known as mixed-pixels, are commonly removed from the data prior to geometric modeling or other downstream processes. The removal of points at the edges of objects introduces error in the geometry of the objects, and object dimensions extracted from the data, such as widths and heights, are usually smaller than the actual values. In many cases, these losses due to removal of points at edges can exceed measurement accuracy tolerances specified in inspection manuals. This paper proposes a model for estimating edge loss in laser scanned data by considering the impacts of various factors, such as scanning distance, density of data and incidence angle on the edge loss. Results from a series of controlled experiments showed that the developed model successfully predicted edge losses in most test cases. Evaluation results using data collected from job sites showed that this model reduced the measurement error due to edge loss by an average of 80% for dense point clouds collected by an amplitude modulated continuous wave (AMCW) scanner, and 38% for relatively sparse point clouds collected by a pulsed time of flight (PTOF) scanner. By adding the estimated edge losses back into the raw dimensional measurements using the developed model, it is possible to significantly improve the accuracy of related measurements and hence improve the accuracy of the geometric information extracted from laser scanned data.

1. Introduction

Accurate geometric information is important for construction quality control as well as monitoring and management of infrastructure systems. Accurate geometric assessments of as-built conditions are needed for active construction quality control for reducing the costs caused by late identification of construction defects, which usually results in costly rework and degradations of building performances [2]. During infrastructure management, accurately acquiring the geometric information of the existing structures is also critical for their condition assessments [3,4,7,10,16,17].

Traditionally, geometric information has been obtained using manual measurement devices, such as measuring tapes and laser tapes, or using surveying instruments, such as a theodolite, a total-station, and global positioning systems (GPS). These tools can only collect sparse measurements at manually selected locations, and, in some cases, require contact with the measured objects. Recently, laser scanning is gaining acceptance as an alternative for geometric data collection within the construction and infrastructure management domain, due to its many advantages over traditional methods. These advantages include higher accuracy, more detailed and comprehensive coverage, remote sensing without being close to the measured objects, and fast data collection rates. A laser scanner is a sensor that measures the 3D structure of an environment by using a laser to measure the distance to nearby visible surfaces. The scanner records the laser pointing as the beam rotates horizontally and/or vertically. The result is a dense set of 3D measurements known as a point cloud (Fig. 1e). Researchers have reported a number of applications of laser scanning in the construction and infrastructure management domain [4,7–11,13,14,16–20,26,28].

Although commercial laser scanners are generally considered accurate and reliable instruments as described by the manufacturers' specifications [21,31,32], certain environmental and sensing conditions lead to data with significantly lower accuracy. One such condition is known as the mixed-pixel effect [15,24]. The mixed-pixel effect occurs at spatial discontinuities in the environment wherever the spot of the laser beam lies partially on two surfaces with different distances from the sensor. In this case, the laser beam is reflected by both the foreground and background surfaces, and the sensor receives a mixture of the two signals. Depending on the underlying laser scanner technology, the resulting range measurement may be reported at the distance to the foreground object, the background object, somewhere in between, or, surprisingly, even at distances closer than the foreground object or further than the background object (Fig. 1d). These noisy points pose questions about the accuracy of point clouds

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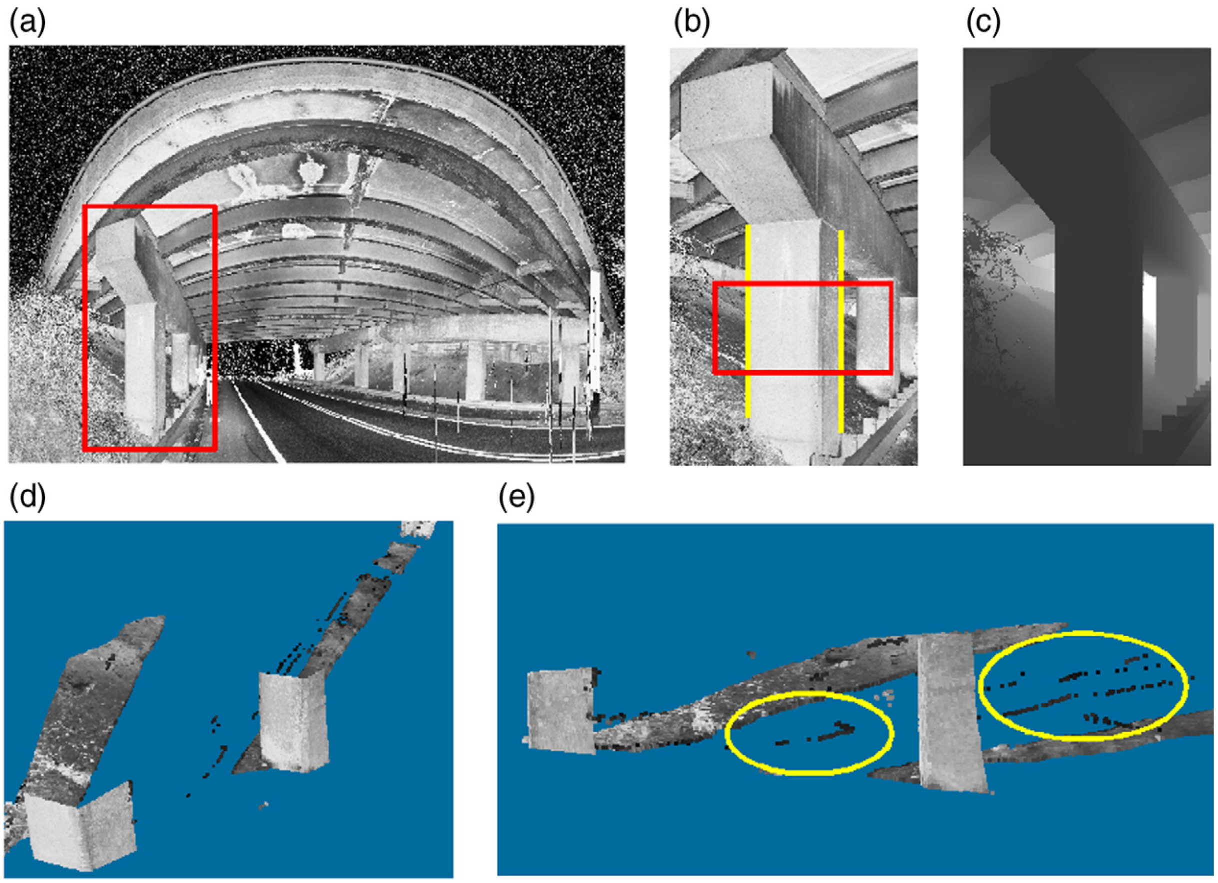

Fig. 1. An example of laser scanned data and mixed-pixels. (a) A laser scan of a highway bridge. The intensity of the laser responses (reflectance image) is shown; (b) A close-up of the bridge column highlighted by the red box in (a); (c) The laser range responses (range image) for the region in (b). Yellow lines indicate depth discontinuities that occur at the column edges; (d) The 3D point cloud corresponding to the region within the red box in (c). The selected region contains two depth discontinuities where mixed-pixels can occur. (e) An alternative view of the point cloud shown in (d). The mixed-pixels, highlighted by yellow ellipses, appear as points in space where no true surface exists. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[22,27]. Some studies have investigated ways to detect and remove mixed-pixels from point clouds [1,5,27,29].

Unfortunately, naïvely removing all mixed-pixels from a point cloud can lead to inaccurate measurements of object dimensions within the data. One case study conducted in this research showed that cleaning mixed-pixels from point clouds causes the measurements of the widths of columns to be substantially smaller than their actual values. This study used the data collected by a commercially available scanner and a commercial 3D reverse engineering environment to construct a 3D model of a bridge. In the reconstructed model, the widths of two surfaces of a column were manually measured at several different heights, which were also selected manually (Fig. 2b). The physical size of that column is 0.914 m × 0.914 m. However, multiple manual measurements from Surface 1 on the column were all smaller than the expected size, ranging from 0.858 m (5.6 cm error) to 0.893 m (2.1 cm error). On the other hand, the width results

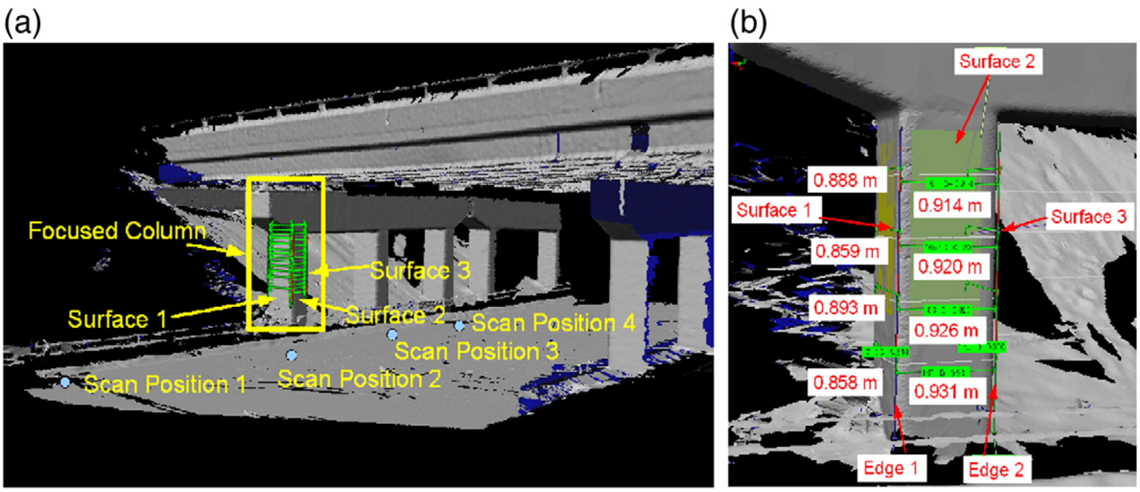

Fig. 2. Measurements on the 3D model with edge effects removed. (a) Bridge 3D model and scanning locations; (b) measurements on a column.